Evaluating Flood Control and Drainage Management Systems from a Productive Efficiency Perspective: a Case Study of the Southwest Coastal Zone of Bangladesh

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Title Page

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Declaration

I, Md. Abdur Rouf, confirm that the research work presented in this dissertation is my own. No portion of this work referred to in this dissertation has been submitted in support of an application for any other degree or qualification anywhere.

Signature

(Md. Abdur Rouf)

Dedication

Dedicated

To my

Late Parents

Abstract

Performance evaluation of flood defence systems is invariably carried out from an engineering perspective overlooking the productivity perspective, thereby leaving a gap in the literature of performance evaluation in the water resources management sector. Two competing flood control and drainage management (FCDM) systems, namely, the 'silt-dredging and regulative-drainage management (SRM)' and the 'tidal river-basin management (TRM)' systems were implemented in the Southwest coastal zone of Bangladesh as safeguards to protect agricultural production. There is a long-standing debate over the appropriateness of these systems in terms of providing conditions for sustainable agriculture. The lead executing agency, Bangladesh Water Development Board, was adamant to implement the hard engineering structural system, the SRM, while the stakeholders (i.e., the farmers and the fisher folk) insisted on the non-structural system, the TRM. However, this work evaluates these two contrasting and competing FCDM systems in terms of productive efficiency, in order to address primarily the gap in the literature of performance evaluation.

The study develops separate econometric models for paddy production and fisheries production with each of the FCDM systems and estimates these models using stochastic frontier analysis to obtain technical efficiency (TE), yield-gap and potential yield increment (PYI) for paddy production, and cost efficiency (CE), cost-gap and potential cost saving (PCS) for fisheries production. The study results reveal that mean TE, CE, yield-gap and cost-gap are respectively 0.782, 0.807, 719.181 (kg) and 12542.71 (tk) with the SRM system, while these estimates are 0.769, 0.762, 807.324 (kg) and 14440.39 (tk) with the TRM in order. These findings indicate that SRM system marginally outperforms TRM system in terms of agricultural productivity. This is despite the SRM being more expensive to deliver, as well as the fact that, due to rise of relative sea-level with the SRM system, it is likely to become increasingly more expensive in the future. In contrast, the TRM system benefits from counteracting the rise of relative sea-level through land accretion by sedimentation in the floodplains in an environmentally friendly way, keeping the maintenance costs low.

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List of Acronyms and Abbreviations

ADB	Asian Development Bank
AE	Allocative Efficiency
BBS	Bangladesh Bureau of Statistics
BWDB	Bangladesh Water Development Board
CE	Cost Efficiency
CEGIS	Centre for Environmental and Geographic Information Service
CEP	Coastal Embankment Project
CES	Constant elasticity of substitution
COLS	Corrected Ordinary Least Squares
CSA	Cost System Approach
DEA	Data Envelopment Analysis
DMU	Decision Making Units
EPWAPDA	East Pakistan Water and Power Development Authority
FCDM	Flood control and drainage management
FGD	Focus Group Discussions
GHG	Greenhouse Gases
GoB	Government of Bangladesh
ha	Hectare
HH	Household
HRS	Hari River System

HYV	High Yielding Variety
IWM	Institute of Water Modelling
IAA	Integrated Aquaculture-Agriculture
IECO	International Engineering Company Inc.
JLMS	Jondrow-Lovell-Materov-Schmidt
KCERP	Khulna Coastal Embankment Rehabilitation Project
LM	Lagrange Multiplier
LR	Likelihood Ratio
ML	Maximum Likelihood
MOLS	Modified Ordinary Least Square
MoWR	Ministry of Water Resources
MP	Muriate of Potassium
NGO	Non-Government Organisation
NPK	Nitrogen, Phosphorous and Potassium
OLS	Ordinary Least Square
PCS	Potential Cost Saving
ppt	Parts per thousand
PWD	Public Works Department
PYI	Potential Yield Increment
PE	Productive Efficiency
SCF	Stochastic Cost Frontier
SEA	Single Equation Approach

SES	South-eastern System
SFA	Stochastic Frontier Analysis
SMEC	Snowy Mountains Engineering Corporation
SPF	Stochastic Production Frontier
SPSS	Statistical Package for Social Science
SRM	Silt-dredging and Regulated-drainage Management
TE	Technical Efficiency
TGS	Teligati-Ghangrail System
TRM	Tidal River-basin Management
TSP	Triple Super Phosphate
UBS	Upper Bhadra System
USAID	United States Agency for International Development
YOP	Yardstick of Productivity

CHAPTER ONE
GENERAL INTRODUCTION

Chapter Structure

Chapter ONE

General Introduction

1.1 Introduction

1.1.1 Background of the Study

Efficient management of some coastal zones emerged as a challenging job owing to their critical ecosystem, diverse natural resources and susceptibility to natural hazards. Protecting the land and water resources in the coastal area from flooding and often subsequent waterlogging, is a concern all over the world, particularly in the tropical regions (Karim and Mimura, 2008; Mirza 2002; Uddin and Yasmin, 2005, p. 11). The rise of sea-level coupled with anthropogenic factors has made this concern greater than ever. For ages, people in the coastal areas have been struggling to save their lives and livelihoods from flooding and waterlogging using past experience and wisdom. Most of these efforts are in line with nature and natural settings (Tutu et al., 2005). On the other hand, governments had a common tendency to adopt hard engineering structural interventions like sea wall, embankments, polders and so on that are mostly incongruent with the natural setup. On many occasions, these technology-fixed structural flood defence systems did not work well, and there is evidence that these systems made the problem worse than before (Syvitski et al., 2009).

Flood control and drainage constitute the core of the management of a coastal area in subtropical regions (Brammer, 2014). There are alternative and often competing flood control and drainage management systems available; hence, identifying an appropriate flood control and drainage management (FCDM) system is very important because of it's large economic and environmental impact. Moreover, there are debates over the priority of a management system over its implementation given that there are alternative systems (ADB, 1993 and 2007; CEGIS, 1998; Tutu et al., 2009). So, it is highly desirable to evaluate the alternative systems in order to select the most appropriate one. What is important here is the method(s) of identification. Actually, alternative management systems should go through comparative performance evaluation with the primary objectives involved being taken into account (Dawson et al., 2004, p. 35). For a flood control and drainage management system, the main objectives are protecting the area from flooding and waterlogging, and providing a better production environment. Accordingly, the identification/evaluation has to be made from both perspectives (i.e., from engineering and productivity perspectives). Unfortunately, this is not the practice in evaluating performance of a flood defence system in the literature; in most of the cases it is done from an engineering perspective in terms of assessing flood risk/frequency, and overlooking the productivity perspective of the system (Hall et al., 2005; Wyncoll and Gouldby, 2015). A performance evaluation which does not consider the productivity potential of an FCDM system, therefore, provides only a partial assessment account (Buijs et al., 2007), as far as the agricultural sector is concerned. As a matter of fact, there is a gap in the literature as performance of flood control and drainage management systems are evaluated only in terms of their potential to protect the area from flooding, and not in terms of the production environments they bring forth. This study, however, addresses this gap in the literature by evaluating FCDM systems based on the production environments they bring forth; more specifically, in terms of productive efficiency as well as the level of productivity of the production units (with them). The debate over the appropriateness of competing FCDM systems appearing invariably in the real world (ADB, 2007; Tujan, 2009), also motivated us to undertake this study.

1.1.2 The gap in the literature of performance evaluation

> "In the past, the provision of flood and coastal defence was sometimes seen as a distinct set of activities or functions. . . . but now it is recognised that these activities must be regarded as part of a coherent flood and coastal risk management activity" (Buijs et al., 2007, p. 1)

In fact, a flood defence system gets involved with many important issues around and needs to be evaluated from wider perspectives; not to be confined to only engineering perspective. However, a wide range of models/approaches from engineering perspectives have been in use studying floods in terms of flood frequency analysis as well as flood risk assessment (Dalrymple, 1960; Rao and

Hamed, 2000; Karim and Chowdhury, 1995; Kidson and Richards, 2005; Ghosh, 2006, p. 16, Defra/Environment Agency, 2004); but none of these approaches covers the productivity issue (see Buijs et al., 2007; Bobée, and Rasmussen, 1995). Flood risk assessment (from an engineering perspective) basically involves analysis of hydraulic loads and the response to those loads by the flood defence system (Buijs et al., 2007; Dawson et al., 2004, p. 43). But all approaches do not hold this idea except the classical ones. In fact, the classical approaches for flood risk/frequency assessment (be it at-site or regional) have been criticised for placing much emphasis on complex mathematical modelling and neglecting completely the understanding of the physical factors (i.e., defence structures) responsible for flood events (Bobée and Rasmussen, 1995), let alone the consideration of production environment in the floodplain area.

The modern approaches, on the other hand, put more emphasis on probabilistic modelling of flood frequency analysis, although more inclusive than the classical ones, still devoid of issues related production environment and productivity associated with the floodplain (Apel et al., 2004 and 2006; Van Manen and Brinkhuis, 2005). Apel et al., (2004 and 2006) applied a dynamic probabilistic modelling system to assess flood risk under the "German Research Network Natural Disasters" project. These studies developed spatially distributed complex models involving hydrological load, flood routing, levee failure and outflow through levee breach, damage estimation and a Monte Carlo framework. Van Manen and Brinkhuis (2005) calculated the risk of flooding of a dyke ring or polder using a new safety concept that was introduced based on total flood risk in the Netherland. However, some of the modern models are extended further to cover wider issues, yet, productivity aspects remain unaddressed. In fact, the modern flood risk models are still dominated by engineering aspects i.e., probabilities of extreme hydraulic loading events and probabilistic performance measures of flood defence infrastructure and its associated reliability etc. (Ayyub et al., 2009; Vorogushyn et al., 2010; Woodward et al., 2011; Wyncoll and Gouldby, 2015).

The probabilistic model with fragility concept is a new approach to performance assessment of flood defence structures (Buijs et al., 2007). The fragility of a structure is defined as 'the probability of failure conditional on a specific loading' (Casciati and Faravelli, 1991). In the case of flood risk assessment, fragility concept represents the link between the likelihood of flood defence response against different hydraulic loading (e.g., water level, wave, the wind, traffic etc.) conditions (Dawson and Hall, 2002, p. 36). This concept is used in many countries including the UK, USA, Germany and the Netherlands. For example, in the UK, Flood Risk Appraisal for Strategic Planning applies fragility curves (Buijs et al., 2007); it has been used in many studies/projects under National Flood Risk Assessment (NaFRA) (Hall et al., 2005, p. 44). However, this new and modern approach is also devoid of issues related production environment and productivity concerning the protected floodplains.

To the best of our knowledge, the most inclusive models available for flood risk assessment takes four aspects namely, source, pathway, receptor and consequences (s-p-r-c) into consideration (see Wyncoll and Gouldby, 2015; Buijs et al., 2007). In this (s-p-r-c) model, the 'source' indicates the hydraulic load such as water level, waves, winds etc.; overtopping and/or breach of the defence structure relate to the 'pathway' or the response to the defence scheme with various hydraulic loads; 'receptors' represents the people, property, infrastructure and the environment within the protected area that can be affected by flood; and finally, the 'consequence' refers to the damage caused by the floods to receptors in the affected area. However, the 'productivity concept' is still absent in these inclusive/comprehensive models keeping the engineering perspective dominant. It seems that there remain two alternative ways to bridge the gap in the literature. Firstly, by incorporating the productivity aspect into the (s-p-r-c) model; or, a separate model can be developed to assess the performance of flood defence system in terms of productive efficiency of the production environment evolves in the floodplain. The study, however, adopts the second option for bridging the gap in the literature, because the first option involves too many engineering matters which is beyond the scope of this study.

1.1.3 Familiarity with the case study

Two competing flood control and drainage management systems—the Silt-dredging and Regulated-drainage Management (SRM) and the Tidal River-basin Management (TRM)—were implemented in two floodplains/depressed areas (locally known as *beel*) in the late 1990s and early 2000s in the southwest coastal zone of Bangladesh in order to protect agriculture from flooding and waterlogging hazards (ADB, 2007; SMEC, 2002a). These two FCDM systems have been functional since their implementation. This study, however, takes the above mentioned flood control and drainage management (FCDM) systems as a case study for addressing the abovementioned gap in the literature. Another issue which motivated us to take this case study is the long-standing debate over the appropriateness of these two FCDM systems. A group of engineers belonging to the lead executing agency, the Bangladesh Water Development Board (BWDB), and the donor agency favoured the SRM system, while the stakeholders (i.e., predominantly the farmers and fisher folk) demanded the TRM. SRM is characterised as a hard engineering structural approach, in contrast, TRM is known as a non-structural natural approach. The debate over these two diametrically opposite perspectives on the solutions to flooding and drainage congestion problems eventually turned into a tension between the local stakeholders and the lead executing agency, and that caused a considerable delay in project implementation[1] (ADB, 2007, p. vi; CEGIS, 1998). Eventually, both of the systems were implemented by the end of the year 2002 (SMEC, 2002a, p. vi) at two severely affected areas under the Khulna Jessore Drainage and Rehabilitation Project (KJDRP), a large project for water resources management in the Southwest coastal zone of Bangladesh (Map 1.1).

Along with the flood control and drainage management, an important objective of implementing these FCDM systems was to safeguard the agriculture, the mainstay of the project command area, as a means for poverty alleviation (CEGIS, 1998; ADB, 1993 and 2007). As it is mentioned in the ADB and SMEC reports:

> "The principal objective of the Khulna-Jessore Drainage Rehabilitation Project is poverty reduction through increased agricultural production in the project area" (ADB, 1993, p. 10; SMEC, 2002a, p. 1.9).

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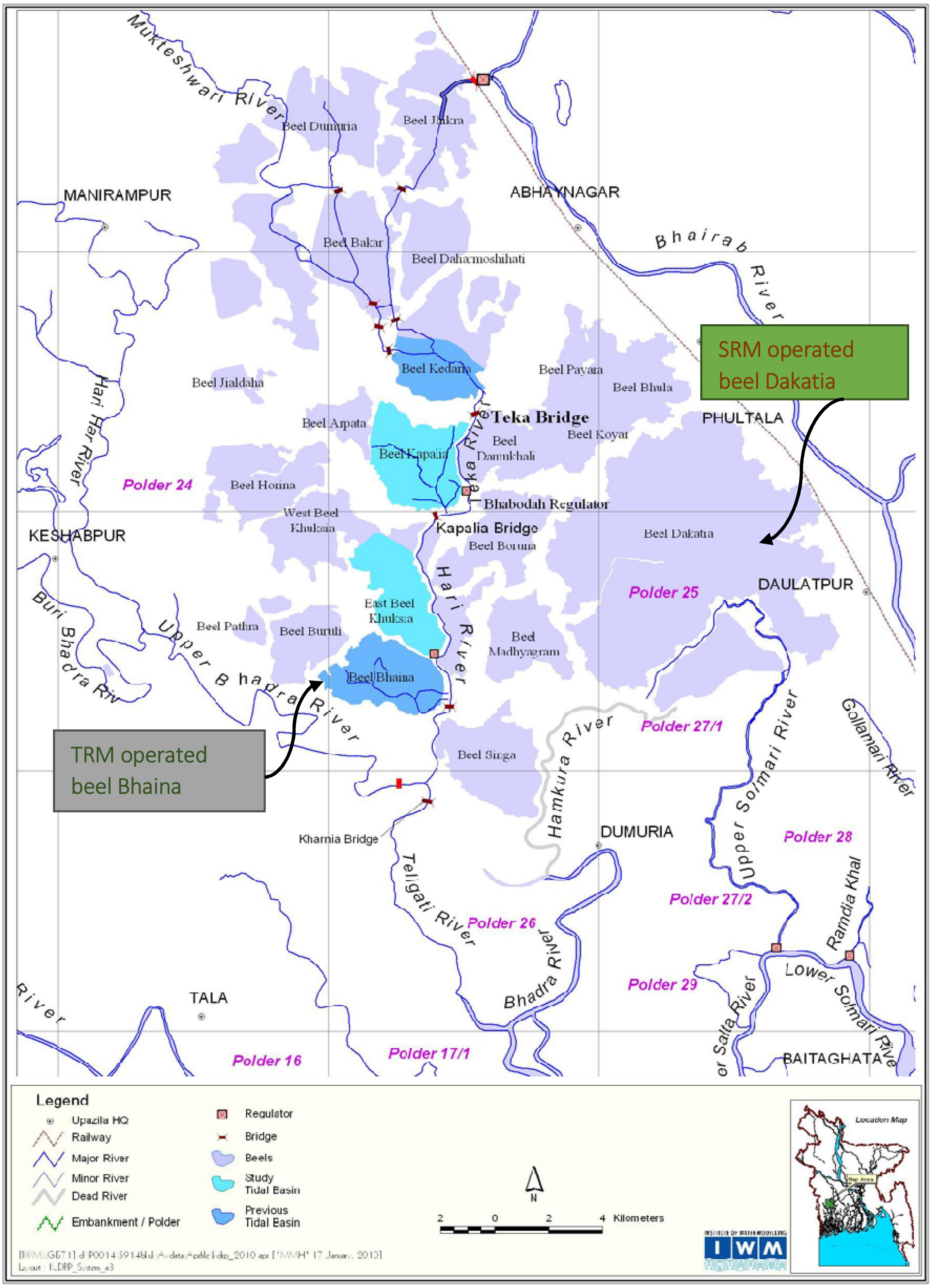
[1]A brief description of the events during the implementation period is presented in section 1.4



Map 1.1: River systems and tidal floodplains/beels in the study area

Source: IWM, Institute of Water Modelling (2005) (Cited in Amir et al., 2013)

1.2 Rationale of the study

(i) From the viewpoints of the gap in the literature and the debate

This study argues that there is a gap in the literature on performance evaluation of flood defence or flood control and drainage management systems that previous studies have evaluated these systems from an engineering perspective neglecting productivity potentials regarding the FCDM systems. Addressing the gap would meaningfully add some knowledge to the existing practice of performance evaluation and thereby contribute to further understanding of the flood defence and drainage management systems. Moreover, performance-based evaluation of FCDM systems against specific objective would help to reach a consensus or, at least, attenuate the debate about their relative strengths and/or potentials; importantly, it would enable us to prioritize investments in alternative flood defence systems.

(ii) From the methodological standpoint

It is well known that any major intervention in the water resources sector of an area affects agriculture of the area significantly. Changes in the agricultural sector occur through modification of the existing production environment of the area, whereby resource usage patterns, employment opportunities, the cost of production, total output etc. take new shapes and sizes. In fact, any major intervention in the water resources sector has significant economic and policy implications. So, it is imperative to understand/evaluate a flood defence system from the perspective of agricultural productivity as far as it relates to agricultural land. Intuitively, different forms of flood control measures/interventions bring forth different types of production environments; hence, understanding an intervention from the perspective of agricultural productivity is very important. To this end, a good number of empirical studies including Eknayake and Jayasuria, 1987; Kalirajan and Shand, 1986; Seyoum et al., 1998; Wadud and White, 2000, performed the comparative evaluation of different types of interventions (in the water resources sector), in terms of agricultural productivity. In fact, it is difficult to ignore productivity aspects when evaluating a flood control and drainage management (FCDM) system which has been applied to an area where agriculture is the mainstay of livelihood. Moreover, when poverty alleviation through agricultural production is the primary goal of an FCDM system, it calls for assessing the system from the perspective of agricultural productivity.

In reality, each sort of flood protection measure exerts a distinctive impact on the topography as well as soil quality of the area, which leads to modify the existing production environment. And this modification, in turn, brings about some changes in the production system. It is, therefore, very likely that a new input-output relationship would evolve for each crop produced compared to the pre-intervention situation. The area in consideration is also important here because a considerable part of the total changes relate to the topography of the area. For example, in an intertidal coastal area, this modification can make significant changes in the production environment since it exploits the tidal flows. Again, if the tidal flows are laden with sediments, this could bring a great deal of change in the production environment. Because of these changes, the production and cost functions would assume new compositions under the changed environment. Now if two or more alternative flood control and drainage management (FCDM) systems are implemented in areas having similar topographic setup, they would very likely end up in different production environments; hence, it is an imperative to evaluate the FCDM systems in terms of productivity performance in agriculture. Estimation of both the technical and cost efficiencies is often recommended for better understanding of the systems.

(iii) From the consideration of a topographically rare study area

The coastal zone of Bangladesh, in particular, the South-western part, has some special topographic features compared to other tropical coastal zones in the world (Brammer, 2014). First, it belongs to the deltaic zone of one of the mightiest rivers in the world—the Ganges—which carries large quantities of sediment from a huge watershed area (of approx. 907,000 sq. km), most of which is comprised of agricultural land. The Ganges River is one of the largest sediment dispersal system in the world (Curray and Moore, 1971; Goodbread and Kuehl, 2000). Second, the coastal zone of Bangladesh is characterised by a dense network of semi-diurnal, tidal rivers and creeks, which is rare in the world (CEGIS, 1998, p. 3; Qaium, 2005). Third, the Sundarbans—the largest mangrove forest in one patch in the world (and also a "World Heritage Site"), lies to the south of this region and it influences the study area in some ways (CEGIS, 1998, p. 5; Islam and Kibria, 2006, p. 21). Combined effects of these factors have given a complex natural setting to the South-western coastal zone of Bangladesh, making it unique (Tutu et al., 2009). However, it is worthy of studying an FCDM system in such a rare and complex topographical setup.

(iv) For an understanding of a unique FCDM system

Reports from earlier studies/evaluations (e.g., CEGIS, 2001 and 2007; ADB, 2007; ADB, 2004) and focus group discussions (see Appendix 4) confirm that both of the FCDM systems have reduced flood frequency in the respective areas since their implementation, albeit not to the same scale. Hence, it is justifiable to evaluate these FCDM systems from the standpoint of agricultural productivity. Most importantly, this study introduces a unique natural flood defence system, the Tidal River-basin Management (TRM), which is based on planned sediment management (IWM, 2005a; Khadim et al., 2013; Amir et al., 2013). TRM addresses flooding and waterlogging problems in an environmentally friendly manner (CEGIS, 1998; Tutu, 2005; Islam and Kibria 2006; Tutu et al., 2009; GEGIS, 2007; ADB, 2007). This type of non-structural coastal flood defence technique contributes to the restoration of the hydrological and geomorphologic dynamics of the tidal rivers and marsh floodplains. Societies and government agencies have been paying much effort in search of a natural flood defence system that would protect their coastal regions in an environmentally friendly way. In the words of Reed et al., (1999, p. 81),

> "The need to understand the processes contributing to marsh sedimentation has become more urgent with the recent recognition of the role of tidal marshes as sea defences, as well as the many restoration efforts currently under way".

Therefore, this study would be of interest to many researchers, government agencies as well as policy-makers. It is expected that a study on TRM would add knowledge to the broader area of water resources and flooding management.

1.3 Past Flood Control Measures in the Study Area

1.3.1 An indigenous knowledge-based flood defence system

The coastal zone of Bangladesh is very much susceptible to flooding because of its geographical location and topographic setup (Mirza, 2002; Choudhury et al., 2004). In the old days, people in the coastal area of Bangladesh used to build low earthen dykes around the tidal flats to prevent tidal intrusion, and wooden sluices to drain off surplus rainwater. Within these bounded areas, indigenous varieties of flood- and saline-tolerant paddy (unhusked rice) were cultivated and bumper harvests reaped. After harvesting, the dykes and sluices would be dismantled to graze cattle and catch fisheries in the (tidal) floodplains (CEGIS, 1998, p. 7); Uddin and Yasmin, 2005, p. 30; Tutu, 2005; Islam and Kibria, 2006; Tutu et al., 2009). These low earthen dykes were called *doser bandh* (embankment constructed by the community) or *ostomashi bandh* (embankment for a period of eight months) in local terms. Actually, these dykes would be maintained for the period approximately from July to December, and would subsequently be breached to keep the enclosures open during the months of January to June in order to allow tides for sediment deposition within the enclosures. The total process was traditionally maintained through community/collective efforts (or *solidarity economy*) and applying indigenous ecological knowledge. Thus, the environment and the ecosystem in the coastal area were in balance. Technically, this system is known as tidal river-basin management (TRM) (CEGIS, 1998; Uddin and Yasmin, 2005, p. 44-45; Islam and Kibria, 2006).

The landlord system (or, '*Zamindari Protha'* in local language), patronised by the state, actually kept the *ostomashi bandh* system (embankment for a period of eight months) operational for its own interest. Under the landlord system, the state would entrust a specific area of land to a loyal person for its utilization; this person was called 'landlord' (or, *'Zamindar'* in local language) and he would act as the local revenue agent of the state for that area. The landlord would allocate the land to the tenant farmers who would pay a proportion of their income/crop to him (the Zamindar) as rent. Since this revenue was largely dependent on crop production, the Zamindars had the dykes (*bandh*) constructed and maintained to save agricultural activities for the sake of the uninterrupted flow of income. However, in 1951, the landlord system (*Zamindari Protha)* was abolished under the East Bengal State Acquisition and Tenancy Act, 1950, and the landlords (*Zamindars)* were stripped of their power and authority. As a result, there were no coordinated efforts to maintain the age-old *ostomashi bandhs* system in terms of repairing the old ones and/or constructing new *bandhs* (dykes); consequently, crop failures followed (SMEC, 2002a; Tutu, 2005; Tutu et al., 2009).

1.3.2 Polderization as a flood defence system

After the total cessation of indigenous flood defence system (i.e., the *ostomashi bandhs* arrangement) there was frequent crop failure, which emerged as a great concerned for the government and the farmers as well. Moreover, there were two devastating floods in the subsequent years of 1953 and1954 (Brammer, 1990; Ali, 2002) that caused unprecedented damage to the coastal zone of Bangladesh. However, realizing the gravity of the scenario, Government of the then Pakistan initiated the Coastal Embankment Project (CEP) in the sixties after the Kruge Mission[2] recommendations. The United States Agency for International Development (USAID) provided the financial assistance to this project. The CEP was basically, a kind of hard engineering structural intervention involving the construction of a network of embankments on the river banks as well as creation of polders[3] (i.e., encirclement of low-lying areas) (ADB, 2007, p. 43; CEGIS 2001, p. 3) that saved the coastal livelihoods providing 'protection from daily tidal inundation by saline waters and from peak seasonal or storm flood levels' (ADB, 1993, p. 8). Pictures 1.1 and 1.2 respectively present a typical polder and a real polder.

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[2]The Krug Mission is a team of experts on water resources management, which was set up in 1957 by the United Nations to review the devastating floods of 1953 and 1954. Following the report of the Krug Mission, the erstwhile East Pakistan Water and Power Development Authority (EPWAPDA) was created. EPWAPDA (now BWDB) prepared a Master Plan for water resources management in 1964 with the help of the International Engineering Company Inc. (IECO) (Brammer, 1990; Ali, 2002).

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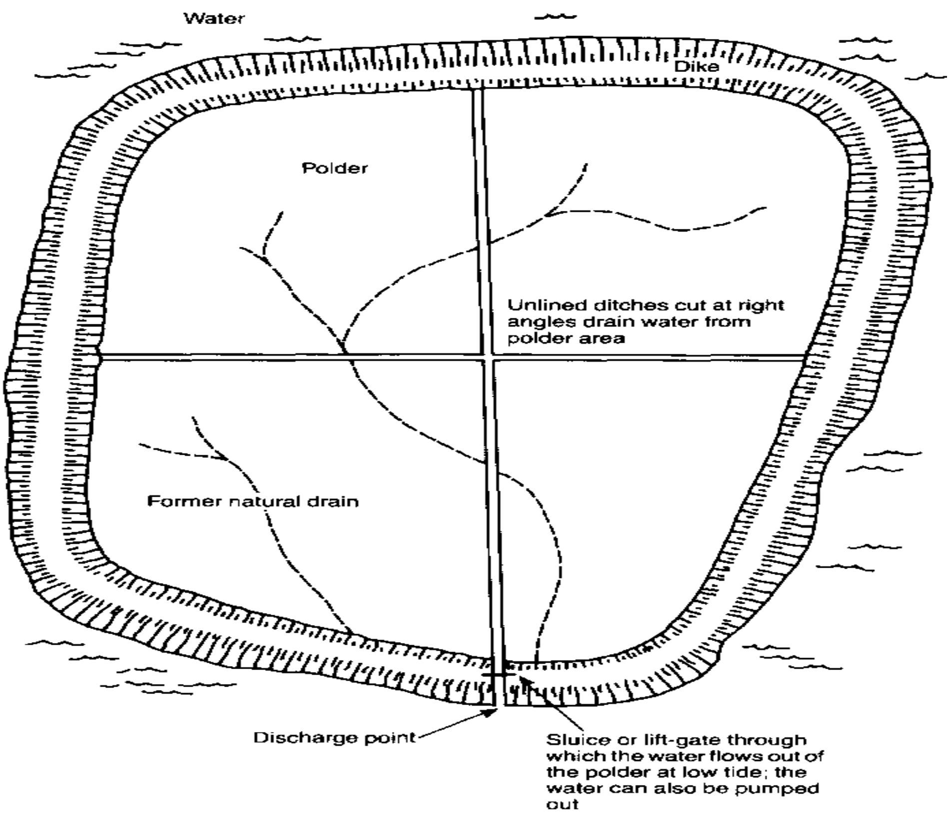
[3]Polder is a Dutch word. A polder is an artificial hydrological entity surrounded by embankments that protect the inside area from outside water, particularly the tides. This concept is practiced in the Netherlands in the context of water resources management (see Ali, 2002; Islam and Kibria, 2006).

However, this technology-fix Coastal Embankment Projects (CEP) provided only a short-term (about 12 years), limited success, and eventually proved to be unsuccessful (ADB, 1993, p. 9; CEGIS, 2001, p. 3). Actually, it had worsened the situation compared to the pre-intervention period, particularly in the Southwest coastal zone of Bangladesh. According to Tutu et al., (2009), polders in Bangladesh, which had provided a short-term limited benefit, and finally led to adverse economic and environmental problems. After fifteen years of the empoldering project, the southwest coastal zone of Bangladesh began to experience the old problems with greater severity, including prolonged waterlogging and drainage channel blockage. These problems first appeared in 1982, when polder-25 (i.e., beel Dakatia area) experienced temporary drainage congestion (Tutu et al., 2009, p. 10). However, continuing process of siltation in the rivers and creeks aggravated these problems progressively.

By mid-eighties, these problems deteriorated to such an extent that there was a humanitarian crisis in the area calling for an immediate remedial action. The accumulated rain water in the polder areas would drain very slowly or not at all, causing prolonged inundation of agricultural lands, homesteads and road communication networks. Suspension of agricultural activities, increasing unemployment rate combined with deteriorating sanitary conditions forced the people in an inhumane living condition (CEGIS, 1998, p. 11-12; Islam and Kibria, 2006). The overall socio-economic and environmental condition was so critical that many people migrated to other places (Uddin and Yasmin, 2005, p. 10). However, to address the problem, the Bangladesh Water Development Board (BWDB), the apex body in the water resources management sector of the government, adopted a couple of rehabilitation projects including the Khulna Coastal Embankment Rehabilitation Project (KCERP), the Second Coastal Embankment Rehabilitation Project (KCERP-II), and the KJDRP, with the financial assistance from the Asian Development Bank (ADB). These projects were taken subsequently due to the poor performance of the earlier ones and/or public protests (ADB, 2007).



Picture 1.1: A typical polder structure

Source: WHO, World Health Organization (1991)

1.4 The Debate over Appropriateness of the FCDM Systems

1.4.1 Earlier rehabilitation projects: The fulcrum of the debate

The saga of the debate between the stakeholders (i.e., the farmers and the fisher folk) and the lead executing agency, the Bangladesh water development board (BWDB), is full of events. This debate truly relates to the research problem. Against the backdrop of the poor performance of the empoldering projects, the pre-polder period endogenous management system—the tidal river-basin management (TRM), locally known as '*zoarvhata khelano*' (or free play of tides)—came to the fore for its reintroduction, albeit, in a revised version. It is noteworthy that the appearance of the first waterlogging problem dates back to the early 1980s when a big floodplain/depressed area (by name *beel* Dakatia, one of the two parts of the study area) endured a prolonged waterlogging hazard. Gradually this problem engulfed the adjacent areas as well. To solve this hazard, the Government of Bangladesh (GoB) initiated the Khulna Coastal Embankment Rehabilitation Project (KCERP) in 1986 covering an area of 31,900 hectares (ADB, 1993, p. 9).

This project was planned to solve the flooding and waterlogging problems with hard engineering structures following the basic principle of polder system. Sensing the adverse impact of this project people rejected it at the very beginning. Since they had a bad experience with the polder system, they demanded for reinstating the TRM system. In 1989, the government undertook another project, the Second Coastal Embankment Rehabilitation Project (KCERP-II), in an area adjacent to KCERP command area. This project was also designed in line with the polder concept (Haskoning and Associates, 1993); whereas people had been demanding throughout for implementation of the TRM system for a sustainable solution to the problem. The media and civil society supported the people and brought the issue to the front line, upholding their arguments. However, the lead executing agency, i.e., the BWDB and the funding agency as well, did not heed the peoples' demands because they were not convinced by the TRM system.

In the early nineties, people were very much distressed by long-lasting flooding/waterlogging and continued deterioration in the quality of stagnant water in the polder areas. Based on their indigenous knowledge they perceived that cutting the embankments is an effective solution to get rid of these problems (see ADB, 1993, p. 9). In the meantime, people became organized and determined to oppose any intervention other than the TRM system. Not only this, they planned to breach embankments where necessary. At one stage, they breached embankments at several critical points, defying the power and authority (ADB, 2007). This breach is technically known as *public cut*[4]. Interestingly, these *public cuts* were made in line with the basic principles of the TRM system and importantly, in most of the cases, these (*public cuts)* yielded favourable outcomes.

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[4]The term 'public cut' is used to describe a breach of the embankment by an organized group people to allow water in or out. The primary objective of the public cuts was to drain out stagnant water from the floodplains/beels; then to allow free play of tides thereby raise the land level in the beels through deposited silt, and improve drainage congestion in the rivers and channels. In fact, a public cut can be termed as an unplanned TRM. These events were taken as an expression of people's collective initiative to mitigate the local environmental problem. To the contrary, in the official and administrative narratives of the concerned government agencies, public cuts were treated as a 'deterioration of law and order situation' and there were police cases against these cuts lodged by BWDB (see SMEC, 2002a, p. B.3; Islam and Kibria, 2006, p. 15).

As a result, there was a new polarization over the FCDM systems in solving flooding and waterlogging problems. People became more confident of the TRM system.

In passing, the government had to suspend the planned implementation of KCERP in 1990 due to the public protests and civil actions including public cuts (breach of the embankment by public) in the project area. Following this suspension, the terms of reference (TOR) of CERP-II were modified (in 1990) in order to combine the KCERP and CERP-II project areas (Haskoning and Associates, 1993; ADB, 1993, p. 1, 9).

1.4.2 Implementation of the FCDM systems and associated incidents

Realizing the extent and gravity of the waterlogging problem, the government of Bangladesh, amidst the aforesaid confrontational situation, initiated a new project by name, the Khulna-Jessore Drainage and Rehabilitation Project (KJDRP) in early 1994, with the financial assistance of the Asian Development Bank (ADB). The project area of KJDRP covers approximately 100, 000 hectare of flat low lying land in the southwest coastal region of the country (SMEC, 2002a, p. vi). Actually, the KJDRP was formulated under the Second Coastal Embankment Rehabilitation Project (KCERP-II) and BWDB was appointed as the main executing agency with the responsibilities for planning, design, implementation and operation and maintenance (SMEC, 2002a; ADB, 2007, p. 3). In this case also, the Bangladesh Water Development Board (BWDB) upheld the principles of polder system, this time with some modifications. Conversely, some prominent water experts favoured the TRM system along with the stakeholders (i.e., the farmers and fisher folk), NGOs and civil society groups (Islam and Kibria 2006; Tutu et al., 2009). Popular opinion regarding indigenous-knowledge-based Tidal River-basin Management approach was disregarded again by the authority. However, BWDB's resistance to adopting a non-structural solution (i.e., the TRM system) against the fixed-structure-based engineering solution heightened the tension between this lead executing agency and the local people (ADB, 2007, p. vi). As in the past, the people in the project command area strongly opposed this project with the same arguments and sensing its adverse impacts they termed it *'old wine in a new bottle'* (Islam and Kbria, 2006; Tutu, 2009).

Meanwhile, the overall environmental condition further worsened with the passage of time. People almost lost their confidence in the BWDB in solving the problem, and they got involved in public cuts again. On 29 October 1997, people made a public cut on the right embankment along the Hari River in order to relieve the waterlogging condition of beel Bhaina and it remained open untill 8 December 2001 (ADB, 2007). This public cut brought remarkable results compared to previous cuts in terms solving flooding and waterlogging problems. The average width and depth of the Hari River downstream to the cut point increased significantly, there were no longer waterlogging in the beel Bhaina, and the beel bed raised enough providing a flood-free condition for farming (SMEC, 2002a, p. 4.5; ADB, 2007; Tutu, 2005; Islam and Kibria 2006, p. 14, 18). However, considering the overall situation, most importantly, the viability of structural solution vs. non-structural solution, the concerned authority (i.e., the Ministry of Water Resources (MoWR), GoB)) realized that it is necessary to have a detailed assessment of environmental condition that these approaches would bring forth. The MoWR decided to get this assessment by an external agency for wider acceptance. In May 1997, the MoWR approached to the Centre for Environmental and Geographic Information Services (CEGIS), a leading consulting organization based in Dhaka, for an EIA/SIA study on the KJDRP. CEGIS responded to this request and carried out the assessment encompassing wider issues and possible scenarios. The study report concluded that TRM was technically feasible, socially acceptable and environmentally sustainable (CEGIS, 1998; ADB, 2007). Drawing on the CEGIS report-1998, the BWDB revised the whole rehabilitation project and agreed to consider TRM approach (ADB, 2004, p. 5) under the KJDRP, although reluctantly (ADB, 2007).

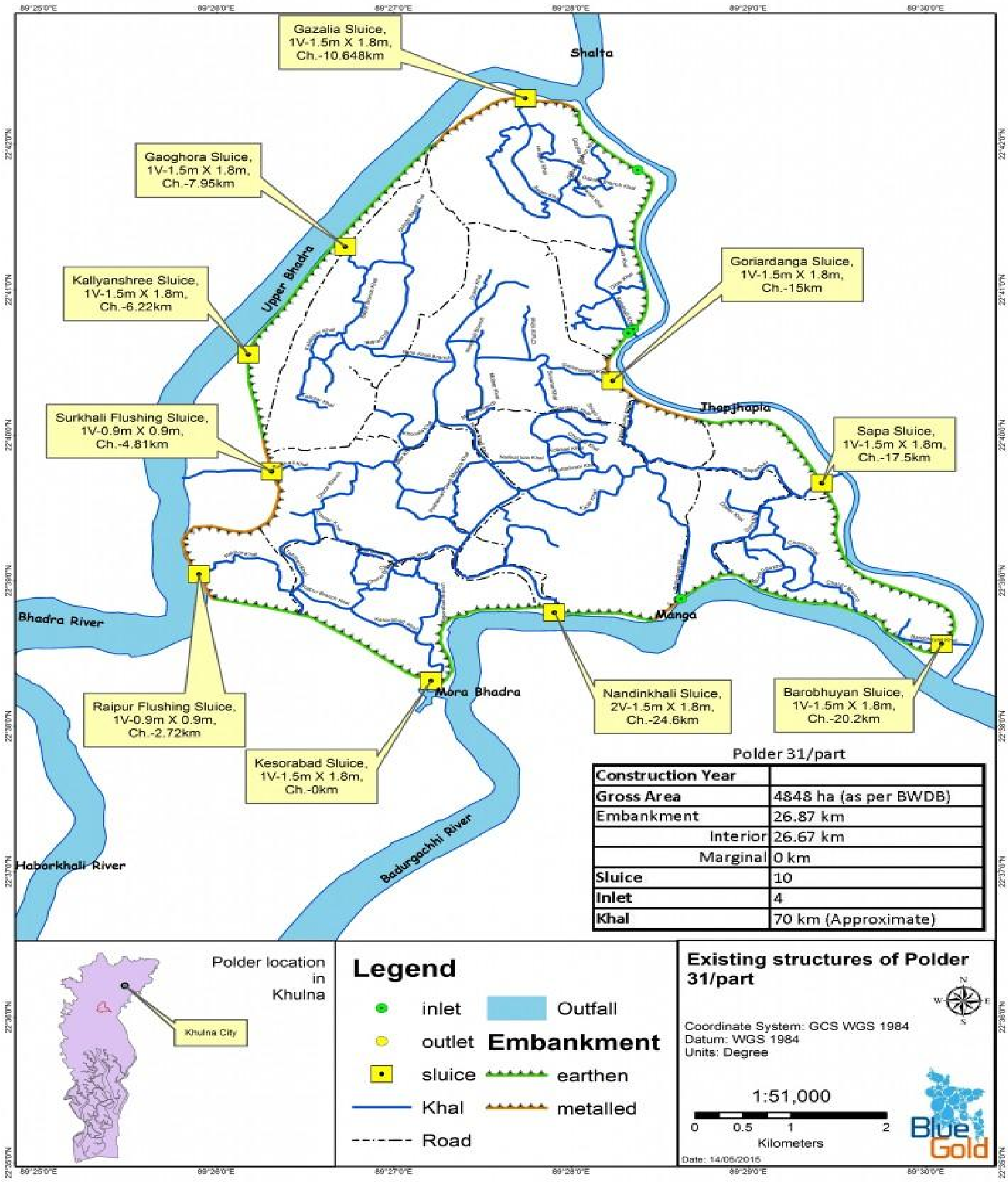
The KJDRP is comprised of four drainage network systems, of which two were most problematic. These are the Hari river system and the South-eastern system (for detail see section 4.4 of chapter 4). In these two severely affected drainage systems, the BWDB implemented the two competing flood control drainage management systems—the Silt-dredging and Regulated-drainage Management (SRM) and the Tidal River-basin Management (TRM). The SRM was implemented for the South-eastern system in the Khulna part and TRM for the Hari Rivers system in the Jessore part. It is worth mentioning that the stakeholders in the

South-eastern system asked for the implementation of the TRM system instead of SRM (CEGIS, 2001, p. 11). In passing, the continued tension between the local stakeholders and the lead executing agency, the BWDB, caused more than three years delay in project implementation (ADB, 2007, p. 4). This study, however, looks into the SRM and TRM systems through assessment of their performance in terms of agricultural productivity.

1.5 Important Features of the SRM and the TRM Systems

1.5.1 Comparing the FCDM systems with a typical polder

The basic principles and operational mechanisms of these two FCDM systems are quite different. SRM is very similar to the polder system, unlike the TRM system. Typically, a polder is a low-lying tract of land enclosed by embankments/dykes that form an artificial hydrological entity, meaning it has no connection with outside water other than through the outlet devices; while the tides of the adjacent rivers are kept confined to the rivers (see picture 1.1). Polders are primarily used for three purposes: (i) 'Reclamation of land' from the large water bodies, such as lakes, sea beds etc. (ii) 'Separation of floodplains' from the direct influence of the sea, particularly the tides and tidal surges; (iii) 'Separation of marshes' from the surrounding water (see Ali, 2002, p. 9). Usually, the ground level inside a polder remains below the surrounding water level; it gradually goes down because of erosion due to the draining of water, land subsidence etc. resulting in gravity drainage problem. The present study, however, deals with this type of drainage problem caused by separating the floodplains (*beels*) from the influence of sea tides (see picture 1.2). This sort of flood management often creates drainage congestion; since the tides are not allowed to go beyond the river channels, the river beds become elevated with sediment deposition from the tides. At the same time, the ground level of the low-lying floodplain (*beel*) inside the polder erodes with the outflow of runoff and it also subsides naturally. At one stage, the elevation of the riverbeds becomes higher than that of the beel bed (or floodplain area) creating a gravity drainage problem. Thus, the hydrology under polders eventually leads to gravity drainage problem and then waterlogging hazards (Qaium, 2005). It is worthy of note that when the area in consideration very large and the problem is severe, it becomes almost impossible to pump out all of the water.



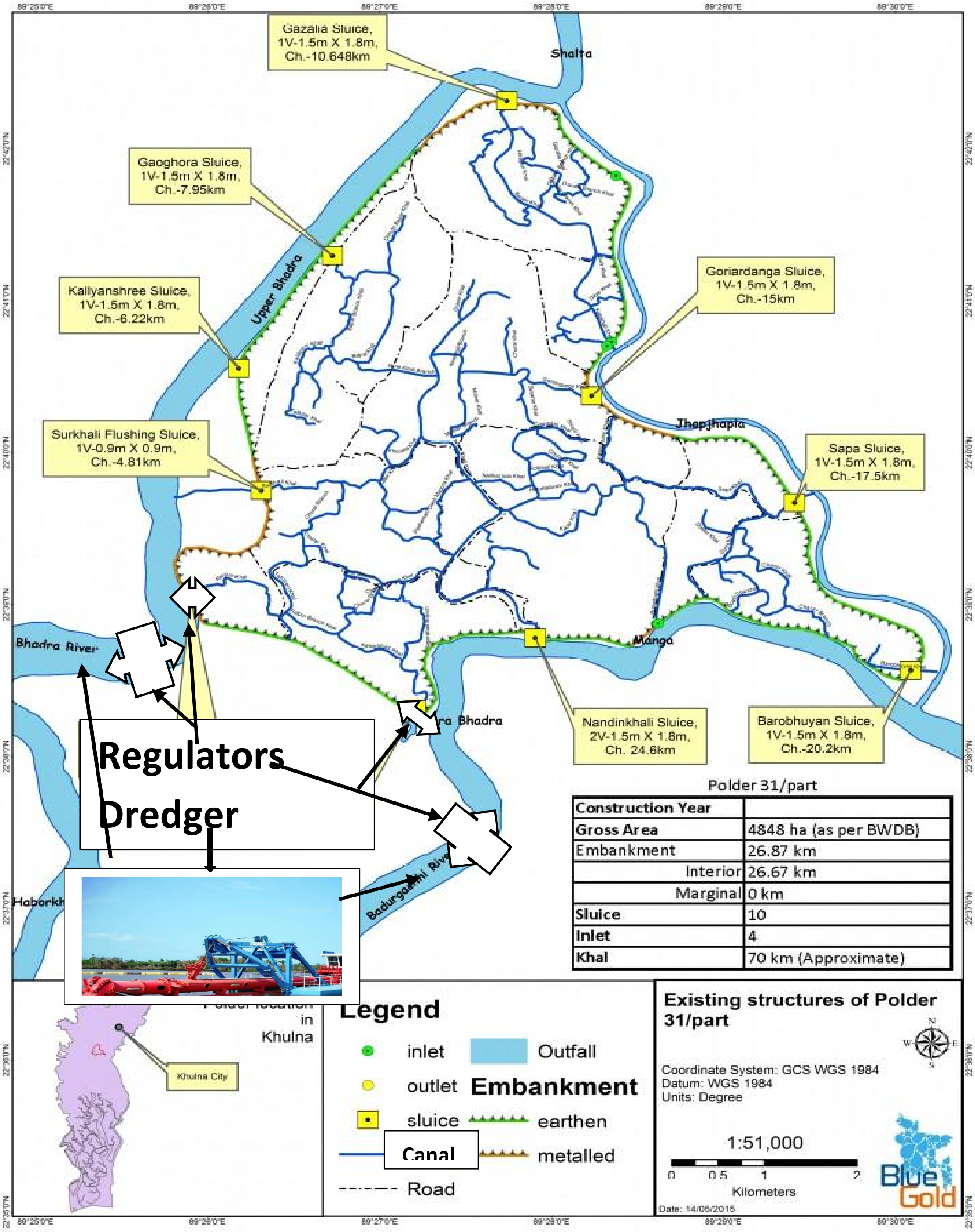
Picture 1.2: A real polder in Khulna district, Bangladesh

Source: Blue Gold Programme (2013-2018)

Note: *Khal* is a Bengali term which refers to canal

1.5.2 The SRM and its features

The basic principle of the Silt-dredging and Regulative-drainage Management (SRM) system is that tides are not allowed to enter into the SRM command area. Flow control (by regulators) and dredging in the river(s) are integral parts of the SRM system. Regulators are constructed at convenient locations, e.g., downstream parts of the river(s) so that sediments deposited beyond the regulators can be dredged out with ease (see picture 1.3). These are the main differences between an SRM system and a polder. Under polder system, no such regulator is constructed for sediment management; rather, there are ordinary regulators/sluices to control the water flow as required which are usually placed at the peripheral boundary of the polder command area (see picture 1.3). So, the SRM system can be termed as a modified version of the polder system. Routine sediment management in the SRM system is a unique practice which is vital to keep it operational (CEGIS, 1998; SMEC, 2002b); indeed, it is the most important aspect distinguishing the SRM system from the so-called polder system. Sediment deposited downstream of the regulator(s) is removed routinely by dredgers. Obviously, the SRM system involves huge costs for its overall operation and maintenance (SMEC, 2002b). It is very likely that an SRM command area is interspersed with small canals and ditches, forming an internal drainage network; hence, the success of the SRM system also depends on the maintenance of the internal drainage network, which again involves considerable costs. However, the most important advantage of the SRM system is that it controls salinity problem effectively as tides are not allowed to enter into the flood protected area (CEGIS, 1998).



Picture 1.3: A polder-based SRM system

Source: Modified from picture 1.2

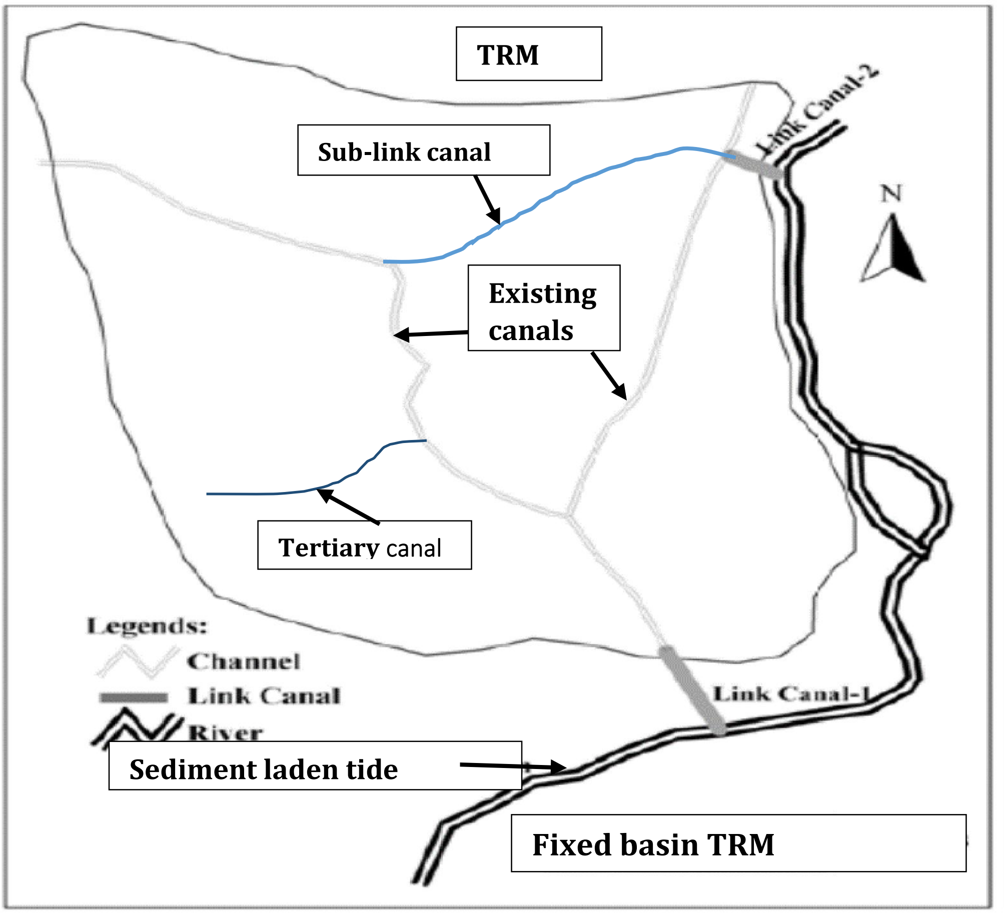
1.5.3 The TRM and its features

The TRM is an indigenous-knowledge based system for coastal flood management which would practice in the old days under the auspices of the local landlords (*Zamindars*). This system actually evolved from the wisdom and long experience of the people in the coastal area of Bangladesh (Tutu et al., 2009). In the course of time, more specifically after the abolition of the landlord (*Zamindari*) system, the traditional TRM system was replaced by the so-called polder system. Under the polder system tides are kept confined to the river channels by building embankment on both sides of the river; as a result, the sediment left by the tides deposits on the river bed. This sediment deposition is the main cause of drainage channel blockage. This blockage mechanism relates to the velocity of tidal flow in the concerned river, as well as the elevation of its bed from the sea level. The velocity of tidal water decreases as the tide proceeds further upstream and sedimentation occurs where the velocity drops below the critical deposition level. Gradual sedimentations cause the storage capacity of the river to shrink, which leads to a further decrease in water velocity, and as a result, sedimentation on the river bed follows. Accordingly, the sedimentation rate is found to be higher at the upstream end of the river under tidal influence and the rate gradually propagates in the downstream direction until it eventually causes the death of the river (Qaium, 2005; CEGIS, 1998). On the contrary, if tides are allowed to travel the floodplain or depressed areas, it could save the river as long as these areas can accommodate the deposits (IWM, 2005b).

Under the TRM system, tidal flows are allowed to enter into the floodplain (*beel*) areas in a planned way so that sediments brought by tides are deposited on the bed of the floodplain (see pictures 1.4 and 1.5). Theses sediment deposits elevate the land level of the floodplain; at the same time, returning sediment-free tidal flows rehabilitate gravitational drainage problems and keep the drainage channel functional. When returning to the sea, the velocity of sediment-free tides becomes stronger; this scours out the sediment deposits on the river bed and washes it away (ADB, 2004 and 2007; Amir et al., 2013; Khadim et al., 2013). In other words, unlike the polder system, the low-lying floodplain areas (i.e., *beels*) are inundated by sediment-laden high tides, which leave sediments until the subsequent low tides; outgoing water gains more velocity being free of sediments, and flashes the channels and rivers, keeping their beds free from sediment (Qaium, 2005). Over time, the features of TRM have been improved; however, TRM is now a blend of traditional practices and modern technology.

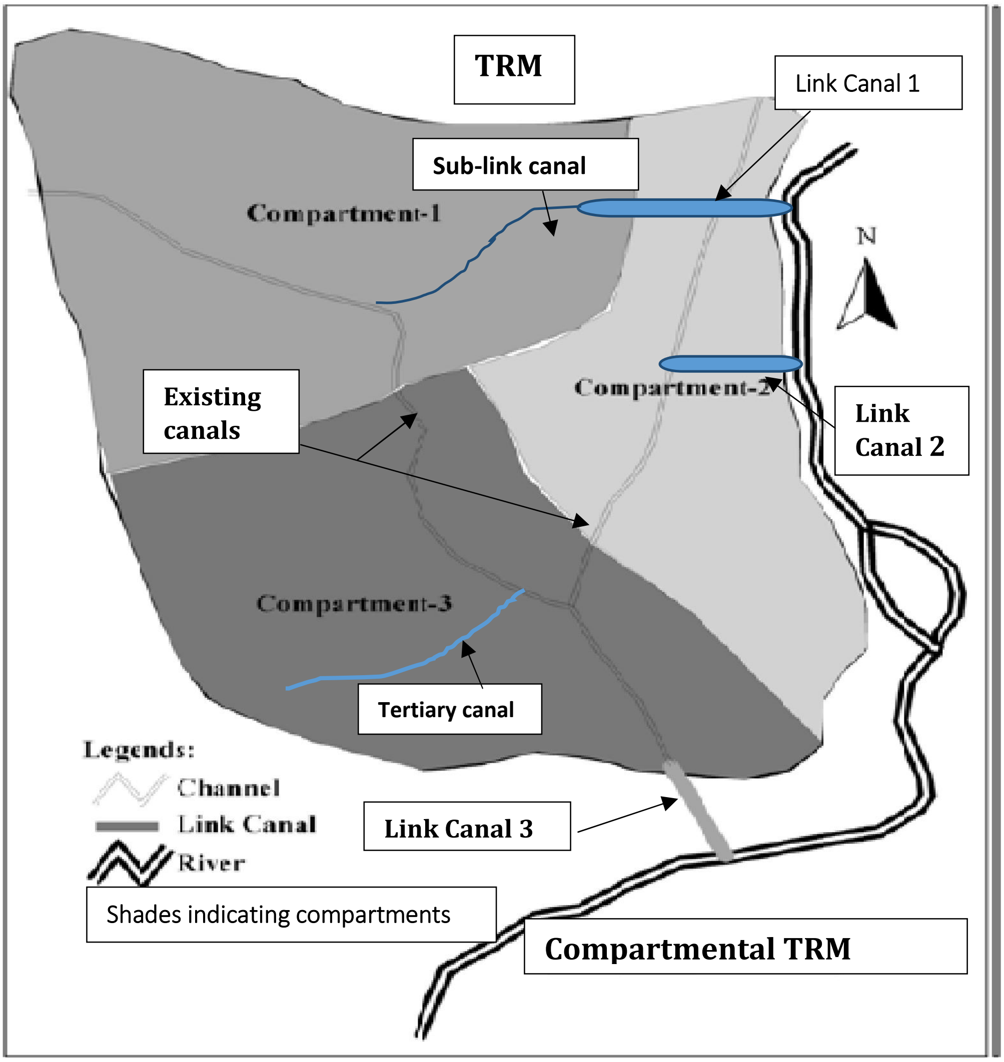
Modalities of TRM

Basin facilities for TRM operation could be arranged in three basic modalities: i) mode of fixed basin; ii) mode of rotational basin iii) mode of compartmentalisation and clustering (CEGIS, 1998, p. 18-19; Amir et al., 2013). Basin here refers to a *beel,* or floodplain. However, a couple of possible combinations could be arranged from these three fundamental modalities. The distinctive feature of the fixed basin mode is that the selected beels or floodplains continue to be inundated by the tides for receiving sediments for a very long period of time. The land acquisition here would very likely to create an insurmountable barrier to the implementation of this modality. Then this raises the question of how long a beel can accommodate deposits born by the tides. However, compared to the fixed basin mode (picture 1.4), the rotational mode is more favourable (ADB, 2007).



Picture 1.4: A whole basin Tidal River-basin Management system
Source: Modified from Amir et al., (2013)

In a rotational mode, the basin area is shifted to another beel after a certain period of time. Usually, this time period lies between 3 to 7 years as was observed in some parts of the southwest coastal zone of Bangladesh. The main problem of this mode is that it requires build new structures for every shift; moreover, it is very likely that it creates obstacles to the migration of fisheries. However, from the viewpoint of impact sharing and silt management, this modality is more practical (CEGIS 1998; Amir et al., 2013).



Picture 1.5: Compartmental Tidal River-basin Management system

Source: Modified from Amir et al., (2013) Under the 'compartmentalisation and clustering' mode, a beel is segregated into several parts (CEGIS, 1998; Amir et al., 2013) as in picture 1.5; or the total required basin area is spread over several beels. Seemingly, this mode is better than the rotational basin mode in terms of sharing the inconvenience and balanced sediment management. However, it necessitates additional structures for peripheral embankments that entail high costs; not only this, additional structures block a wider range of obstacles to fish migrations and agricultural practices. However, considering overall merits and demerits, the rotational basin mode seems to be more practical; in fact, this modality has been practiced since the reintroduction of the TRM system in the study area.

1.6 The Overall Goal of the Study

Performance evaluation of the two competing flood control and drainage management systems—the SRM and the TRM—in terms of agricultural productivity is the primary goal of this study. Since the management systems deal with flooding and waterlogging hazards, it is necessary to consider a year-round phenomena in the evaluation process. This entails inclusion both of the two dominant crops, paddy and fisheries, grown throughout the year with the FCDM systems. In fact, these are the dominant crops in the study area (see Uddin and Yasmin, 2005, p. 14; Tutu et al., 2009). However, farming practice, production processes and the cost of production for one crop significantly differ from those of the other. For example, paddy is produced under such a farming practice that upholds Zellner et al., (1966) argument of expected profit maximization, while fisheries production relates to commercial farming, where cost minimisation motive is predominant. Considering these contrasting behavioural attitudes in the overall production system, two different analytical models (e.g., stochastic production frontier (SPF) model for paddy production and stochastic cost frontier (SCF) model for fisheries production) are applied to assess the FCDM systems.

1.6.1 Specific objectives

The following are the specific objectives of the present study.

(i) Estimation of productive efficiencies (following Zelner et al., (1966) argument):

(a) technical efficiency of paddy production

and

(b) cost efficiency of fisheries production

(ii) Measurement of yield-gap and cost-gap:

(a) the extent of slackness (i.e., the difference between potential output and actual output) in paddy production,

and

(b) the extent of excess cost (i.e., the difference between potential/efficient cost and actual cost) involved in fisheries production.

(iii) Assessment of 'potential yield increment' and 'potential cost savings':

(a) additional output (e.g., paddy per acre) that could be produced if the farm were technically efficient,

and

(b) the amount of cost (for fisheries production per acre) that could be saved if the farm were economically efficient.

(iv) Accounting input usage costs for paddy production:

(a) input usage cost/pattern with respect to yield,

and

(b) input usage cost with respect to land utilisation.

(v) Formulation of policy recommendations towards making the management systems more productive and proactive for sustainable agriculture.

1.6.2 Research and sub-research questions

In order to achieve the above objectives, the research and sub-research questions to be addressed are as follows:

(A) What is the technical efficiency score for paddy production with each of the FCDM systems? The associated research sub-question follows: how does each individual input's productivity (i.e., partial elasticity of output) vary with the systems? More specifically, what type of input-output relationship exists with each of the management systems?

(B) What is the cost efficiency score for fisheries production with each of the management systems/production environments? Accordingly, the research sub-question is: to what extent an individual input price/cost contributes to the total cost of fisheries production with each of the FCDM systems?

(C) What is the measure of average 'yield-gap' for each of the management systems and then the extent of variation between them (average yield-gaps)? The associated research sub-question comes up: what is the rating of 'potential yield increment' on average against each of the management systems and how does the rating vary with efficiency level?

(D) What is the measure of average 'cost-gap' for each of the FCDM systems and the extent of the difference between the average cost-gaps? The associated research sub-question is: what is the rating of 'potential cost saving' on average against each management system and how does the rating differ at different efficiency levels?

(E) Finally, what is the input usage cost/pattern for paddy production with each of the competing management options? Hence, cost accounting is done per unit of yield and per unit of land?

To deal with the questions in subsection (A), stochastic production frontier (SPF) models for paddy production with SRM and TRM systems are estimated using the maximum likelihood (ML) method. Similarly, for the questions in subsection (B), stochastic cost frontier (SCF) models for fisheries production with SRM and TRM systems are estimated using the same method. The main question in the (C) and (D) subsections are addressed by developing statistical formulae (e.g., for yield-gap, cost-gap etc.) based on the definitions that are consistent with the study; while mathematical manipulations of these two formulae are made to answer the rest of the questions in these two subsections. Finally, answers to the questions in subsection (E) are extracted from descriptive statistics of household survey data, since this study follows probabilistic sampling techniques.

It is expected that the outcomes of this study would reveal the relative performance of the two competing FCDM systems regarding their contribution to agriculture at the first place, then provide valuable information about the factors in the econometric models to formulate policy prescriptions towards a sustainable agriculture with them (the management systems). At the same time, focus group discussions would furnish necessary information to support the policy prescriptions and improve the efficacy of the FCDM systems.

1.7 Organisation of the Thesis

This dissertation consists of eight chapters, which can broadly be subdivided into four parts based on the discourses they cover. The first part presents the context of this study and relates it to other similar studies. This part includes the first two chapters. Chapter One, the **General Introduction**, provides an overview of the research problem as well as the background of the study. Specifically, the research problem relating to performance evaluation of the two competing flood control and drainage management (FCDM) systems – the SRM and the TRM. A brief account of the overarching debate about the implementation of these two FCDM systems is presented subsequently. The following section then illustrates the technical and operational aspects of the FCDM systems for a better understanding of the research problem. At the end, this chapter elaborates the research questions and sub-research questions in relation to meeting the objectives of the study.

Chapter Two, **Conceptual Issues and Literature Review,** establishes a link between this thesis and the works of others by synthesising research methodologies, analytical tools and their applications. This chapter starts by introducing the criteria for performance evaluation of production organisations/environments and the principal analytical tool, the stochastic frontier analysis (SFA), then provides a survey of previous empirical studies relevant to the present work.

The second part of this thesis consists of chapters 3 and 4, illustrates the analytical foundation of the work. Chapter Three, the **Theoretical Framework and Methodology,** thoroughly discusses the methodological issues related to the estimation of productive efficiency providing their theoretical underpinnings. At the outset, the chapter illustrates the theoretical bases of productive efficiency and frontier analysis. In the subsequent sections, statistical techniques for estimation of frontier models and prediction of productive efficiencies are presented. The functional form of the a model and data manipulation play an important role in the estimation of parameters and efficiency estimates, and these issues are discussed in the following sections. Statistical methods of measuring some important yardsticks of productivity are also discussed in the chapter. Furthermore, the chapter addresses the basic principles of hypothesis testing by the likelihood ratio (LR) test with reference to stochastic frontier analysis and finally, outlines the sampling techniques of collecting primary data. Chapter Four, **Study Area and Data Collection,** as the title indicates, covers two important sides of this study. Firstly, it identifies the study area as a wetland type, then describes the area with respect to its topography and hydrology, since these aspects matter to agricultural productivity. In the following section, an outline of gher-farming is presented. The second portion of the chapter describes the techniques of probability sampling applied to collect primary data from a household survey and then points out the shortcomings of the sample survey and the strategies adopted to overcome them.

Chapters 5, 6 and 7 constitute the third part of the thesis, which is considered to be the heart of this dissertation since the chapters in this part deal with data analysis, presentation of results and comparative evaluation of the competing FCDM systems. Chapter Five, **Stochastic Production Frontier Analysis of Paddy,** investigates which one of the two competing management systems provides more favourable conditions for growing paddy. As part of this investigation, the chapter develops the stochastic production frontier (SPF) model for paddy production with each of the flood control and drainage management (FCDM) systems—SRM and TRM, estimates the models and compares the FCDMs based on technical efficiency. In the similar fashion, chapter Six, **Stochastic Cost Frontier Analysis of Fisheries Production,** continues to do the same for fisheries production applying a contrasting estimation technique with the stochastic cost frontier (SCF) model. The chapter develops stochastic cost frontier (SCF) models for fisheries production, estimates the models and compares the FCDMs based on cost efficiency. In each of these two chapters (5 and 6), several types of hypotheses are tested by choosing appropriate specifications for the models concerned. Apart from productive efficiency estimates, this study employs some yardsticks of productivity to measure the performance of the two competing management systems. Chapter Seven, **Yardsticks of Productivity and Performance,** deals with some of the yardsticks of productivity used in agriculture. Along with the basic yardsticks of productivity (e.g., yield-gap and cost-gap) the chapter calculates two important variants, potential yield increment (PYI) and potential cost saving (PCS). Providing a general idea about these yardsticks, the chapter develops the formulae for measuring them and then compares the FCDM systems based on the findings.

The last part of the thesis, chapter Eight, **Summary and Conclusions,** recapitulates the core issues of this work including the research questions, analytical techniques and the findings to draw a conclusion thereon. The chapter proceeds in accordance with the organisation of the thesis. Recalling the research problem, the chapter narrates how the research questions have met the objectives of this study with different types of estimates and measures, whilst the subsequent section provides a conclusion to this study based on empirical findings.

Thereafter, the thesis elaborates on the policy recommendations, contributions to the production of knowledge and limitations of the study. Finally, the chapter identifies areas of future research after drawing an overall conclusion.

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CHAPTER TWO
CONCEPTUAL ISSUES AND LITERATURE REVIEW

Chapter Structure

Chapter TWO

Conceptual Issues and Literature Review

Objectives and Organisation of the Chapter

The aim of this literature review is to contextualise the study and justify the research methodology linking the present work with the works of other researchers. This study basically deals with performance evaluation from a productivity perspective. The first section of this chapter briefly presents the importance of literature review. The second and third sections review the conceptual issues relating to performance evaluation including the criteria for performance assessment, alternative methods of estimating productive efficiency and features of frontier analysis. While alternative functional forms of the frontier models for estimating productive efficiency are presented in section four, and section five discusses applications of productive efficiency for performance evaluation in agriculture. Estimation of cost/economic efficiency and some useful yardsticks of productivity are illustrated in sections six and seven respectively; finally, section eight presents the summary and conclusions.

2.1 Introduction

The literature review helps to establish the place of a research work within the international academic literature, and at the same time, it verifies that the work has not already been done (Houser, 2007). It investigates primarily those issues of other works that relate to the work under consideration and then presents them in a way that justifies and/or strengthens the methods/approaches adopted. Generally, a literature review highlights the weaknesses and strengths of alternative analytical tools and methodological approaches applied to other works and thereby warns against mistakes. Thus, a literature review enhances the ability of a researcher to carry out a research in a meaningful way and thereby establishes the creditability of the researcher (Leary 2004). Likewise, the present literature review provides insights into choosing analytical techniques and designing the methodological framework of the present research work in the field of performance evaluation. Performance evaluation of a production organisation can be carried out in several ways (Neely et al., 2005); however, this review confirms that the vast majority of empirical studies in the field of performance evaluation have used estimates of 'productive efficiency' where stochastic frontier analysis (SFA) is the principal analytical tool.

However, the purpose of this literature review is threefold: (i) to introduce the concept of productive efficiency and familiarise important features of the stochastic frontier analysis (SFA); (ii) to provide an overview of empirical studies with frontier analysis; and iii) to make a critical evaluation of methodological approaches to estimating productive efficiency, particularly for cases where comparative performance evaluation of different production organisations/environments is involved. The body of literature on comparative performance evaluation with SFA is vast (Neely et al., 2005); however, this review concentrates mostly on agricultural economics and resource management; hence, the list is comprehensive but far from exhaustive. Furthermore, detailed accounts of some of the important topics/issues are given in the relevant sections of the following chapters.

2.2 Criteria for Assessment of Productivity Performance

2.2.1. Introducing productive efficiency

Farrell (1957) coined the term 'productive efficiency' and highlighted the importance of this concept in production economics. In his seminal paper, the author had illustrated the technique of measuring productive efficiency and then provided an empirical application of the method to agriculture in the United States. Farrell (1957) begins with the statement:

> "The problem of measuring the productive efficiency of an industry is important to both the economic theorist and the economic policy maker. If the theoretical arguments as to the relative efficiency of different economic systems are to be subjected to empirical testing, it is essential to be able to make some actual measurements of efficiency. Equally, if economic planning is to concern itself with particular industries, it is important to know how far a given industry can be expected to increase its output by simply increasing its efficiency, without absorbing further resources" (Farrell 1957, p.1).

The above extract conveys the definition, importance and wider scope of productive efficiency in the arena of production economics. First, the words 'industry' and 'economic systems' broaden the purview of the estimating model and its applicability. Second, the outcome of this analysis can provide necessary information which is crucial in policy making. Third, it gives a notion of productive efficiency, as well as relative efficiencies, of competing production units. It is noteworthy that Farrell used the terms 'productive efficiency' and 'efficiency' synonymously.

Efficiency has three types of interpretation: technical, allocative and economic, or cost; while, economic efficiency is made up of technical and allocative efficiencies (Farrell, 1957; Schmidt and Lovell, 1979). In general, efficiency measurement offers a comparison between actual and optimal performances, assuming that optimal performance is located in the 'best practice' production path (Førsund et al., 1980; Green 2008). In textbook literature, the technical relationship between inputs and output (or costs and output) is termed as production function (or cost function). However, in the efficiency measurement literature, the word 'function' is usually replaced by 'frontier' to distinguish between them, since the term 'frontier' offers the maximum output that is technologically feasible (Coelli et al., 2005, p.12).

2.2.2 Defining technical, allocative and cost efficiencies

The analysis of the stochastic production frontier is based on the assumption that the output of each farm is bounded by a frontier and the position of this frontier can vary across farms, or over time for the same firm (Aigner et al., 1977; Førsund et al., 1980), which ensures its stochastic nature. This randomness allows farms to be technically inefficient relative to their own frontier. Inefficiency in a production process happens in two ways: technical and allocative. A firm is inefficient technically because it fails to produce maximum output from a given output bundle or over-utilises all input equi-proportionately for the same output bundle. Thus, a technically inefficient firm may also suffer from allocative inefficiency. By definition, allocative inefficiency refers to the usage of inputs in the wrong proportions and, thus, the firm fails to obtain the marginal value product of an input that is equal to the price of that input (Schmidt and Lovell, 1979). Moreover, allocative efficiency primarily relates to the skill of the operators in determining the right proportions of inputs (given the level of prices) into the production process; in this way, it receives little or no influence from the production environment or intervention under which production takes place. This is why, in many empirical studies, only technical efficiency estimates were used in relative performance evaluations. According to Kalirajan and Shand (1999), the idea of technical efficiency is central to measuring the performance of production units.

On the other hand, in common with technical efficiency, cost efficiency also reflects the effects of the production environment or the intervention. Therefore, when competitive production environment or management systems are compared based on productive efficiency, either technical or cost efficiency or both, can be considered. Hence, allocative efficiency is not so relevant, since the credit for allocative efficiency is ascribed absolutely to the producer(s) and not to other agents involved in the production process. The above discussion is congruent with the view of Førsund et al., (1980, p. 15), who state:

> "It is well-known that either the cost function or the production function uniquely defines the technology; which one is to be estimated depends on one's assumptions and/or data".

Before starting production activities, producers usually consider two distinct objectives: i) optimal utilisation of inputs, and ii) minimising cost of production. Kumbhakar and Lovell (2000, p.15) labelled the first objective as an *elementary level* *objective* and the second one as a *higher level objective* and associated them with technical and cost efficiencies respectively. The main focus of an 'elementary level objective' rests on the avoidance of wastage and the attainment of maximum output, or minimisation of input usage for a given level of output. Hence, productive efficiency is measured in terms of technical efficiency and the score increases with the level of effectiveness of resource utilisation. Similarly, a 'higher level objective' of the producers centres on producing a given level of output with minimum possible cost. In this case, productive efficiency is measured by cost efficiency and the score increases as the costs fall. Indeed, 'efficiency scores are performance measures on the basis of which production units are evaluated' (Reinhard, 1999, p. 3). In sum, it is sufficient to estimate either technical efficiency or cost efficiency in evaluating the performance of production environments. However, it would be better to consider both technical and cost efficiencies for an overall evaluation.

2.2.3 Usage of productive efficiency

Productive efficiency estimated by stochastic frontier analysis (SFA) is an approach that fits into a wide variety of firms and decision-making units (DMU)[1] in diverse sectors and sub-sectors of production economics. As Coelli et al., (2005, p. 1) described, SFA can be applied to a wider range of production units from private sector firms (e.g., garments factories, internet providers, travel agencies, restaurants, airlines, port terminals and so on) to public sector firms (hospitals, schools and so on), and even to smaller production units within a firm (e.g., branches of a bank, retail stores, outlets of fast food chains etc.). In fact, a large number of empirical studies have exploited SFA in estimating productive efficiency to address policy concerned issues that relate to the performance evaluation of production activities.

[1]Decision-making unit (DMU) refers to relatively smaller productive entity which is less than a firm or part of a firm (Coelli et al., 2005, p. 1).

Economic researchers and policy makers applied this approach to varying specifications in many concerns from goods to service producing units (see Otieno et al. 2014; Bokusheva et al., 2012; Iglesias et al., 2010; Bravo-Ureta and Rieger, 1990; Kumbhakar et al., 1989; from profit making to non-profit making production entities (see Färe et al., 1986; Diewert and Nakamura, 1999; Jones, 2006; Jones and Yu, 2008). Indeed, the basic purpose of productive efficiency estimation relates to the comparative performance evaluation of the production entities via the production environments. More specifically, this efficiency estimation searches for the input combination which is most productive. Thus, efficiency estimation is a relative concept where the performance of a production unit is compared to a benchmark or ideal (Green, 2008). The logic here is that, with a change in the state of the production environment and its set-up, the ratio of input combinations changes, determining new input-output relationships; these new relationships lead to varied output (or cost of production), which in turn determines the efficiency level.

Reasonably, it is the efficiency estimates that can be used to evaluate the management and/or technology under which the production units are being operated. In the agricultural sector, changed input combinations, as well as input-output relationships re-determined by new technological and management interventions, are very complex since a good number of factors are involved here. These interventions may appear in many forms, for instance introducing a newly developed technique in agriculture such as an irrigation project, drainage and flood control project, adaptation of new technology, e.g., mechanisation of farming activities; imposing governmental policy e.g., quota system, credit availability, price support and so on (Coelli, 1995b). As a matter of course, existing production and cost functions relating to the production units using these interventions (then) assume different forms and patterns in the changed environment. However, it often becomes necessary to know the relative advantages of these interventions for policy reasons.

2.3 Estimating Productive Efficiency with Frontier Analysis: An Overview

2.3.1 Alternative methods of estimating productive efficiency

The body of literature on efficiency estimation is vast, covering a number of issues and approaches. In production economics, the efficiency of a production unit is most commonly estimated with the concept of frontier analysis. There are several reasons behind the preferential use of frontier models in the pursuit of efficiency estimation. First, unlike the traditional regression analysis, the idea of a frontier analysis is consistent with the underlying economic theory of optimising behaviour. Second, estimation of efficiency in terms of deviations from a frontier (or best-practice level) has logical interpretations. Finally, information about the relative position of production units in terms of their efficiency measures has many policy implications (Bauer, 1990).

Frontier approaches to estimating productive efficiency comprise several alternative methods. However, empirical analysis of a production organisation's efficiency can be categorised into two broad paradigms: non-parametric and parametric. The non-parametric paradigm is assimilated into Data Envelopment Analysis (DEA) which applies mathematical programming techniques to produce 'efficiency *measures',* while the parametric paradigm predominantly involves frontier analysis, which applies econometric techniques and heavily relied on statistical methods to produce 'efficiency *estimates*'[2] (see also Cornwell and Schmidt, 2008, p. 723). The main advantages of the DEA approach are: no explicit functional form of the data in consideration is required for analysis (Bauer, 1990; Coelli, 1995a) and it can easily accommodate multiple outputs. The downside of DEA is critical; being non-stochastic,

[2]The terms 'efficiency *measures*' and 'efficiency *estimates*' are appropriately chosen by Horrace and Schmidt (1996).

the DEA model takes no account of statistical noise; actually, it reports statistical noise as inefficiency. Thus, it is expected that measures of inefficiency in non-stochastic frontier models like DEA will be greater than those of a stochastic frontier model like SFA. Given the inherent nature of variability in agricultural production due to random shocks, weather, disease and pest infestation etc., the assumption made in DEA that all deviations from the frontier are associated with inefficiency is hard to accept (Coelli and Battese, 1996; Coelli, 1995a). Furthermore, the authors also argue that in the literature of agricultural economics, the Stochastic Frontier Analysis (SFA) has been the preferred approach. In fact, the SFA approach has overwhelmingly surpassed the DEA approach in many respects. The strongest argument in favour of SFA is that it provides a straightforward basis for statistical inference, involving point estimates, construction of standard errors and confidence intervals for efficiency estimates. Of course, the strength of the SFA approach comes from arbitrary distributional assumptions (of the error terms) in order to obtain efficiency estimates (Horrace and Schmidt, 1996). However, the merits of SFA outweigh its demerits; this is why SFA is so popular.

Like SFA, distance functions can be used in analysing productive efficiency of production organisations (see Rahman et al., 2011; Coelli and Perelman, 1999; Coelli and Fleming, 2004). The underlying concept of a distance function involves radial contraction of input given an output vector, or expansion of output given an input vector. Thus, there are two types of distance functions: input distance function and output distance function. The strength of the distance function approach is that it is useful in dealing with multiple-input and multiple-output production systems (Coelli et al., 2005, p. 47). Unlike SFA, the distance function approach does not require the specification of behavioural assumptions of the production technology, such as cost minimisation or profit-maximisation. However, there are some other serious limitations of this approach. Firstly, it is likely that the composite error term may be correlated with the explanatory variables (see Atkinson et al., 1998; and Atkinson and Primont, 1998; Coelli et al., 2005, p. 265). This is a very serious issue as it violates the underlying assumption of the stochastic frontier model. Secondly, the concave and quasi-concave properties of economic theory are not always satisfied by the estimated input distance functions. These issues lead to biased estimates and then misleading conclusions regarding the relative efficiency levels of production units. Another consideration in avoiding the distance function approach is the quality/nature of the data. If data contain zero-value observations, the multi-output distance function is not an appropriate method of data analysis (Singh et al., 2009).

2.3.2 Frontier analysis of a non-parametric model: The DEA

The data envelopment analysis (DEA) is built on Farrell's (1957) piecewise linear convex hull approach to frontier estimation. Using a mathematical programming problem Charnes et al., (1978) redesigned the approach and termed it data envelopment analysis. This approach surpassed the previous approaches of its kind suggested by others including Shephard (1970) and Afriat (1972), and at the same time, received wider acceptance (Coelli et al., 2005; Coelli, 1995a). Over time DEA has been developed in terms of both theoretical robustness and improvements of models to consider practical situations. Data variation is also seen as a significant improvement in the methodological development of DEA. Data values in the earlier DEA models used to be fixed and known; now there has been literature where data may exhibit 'variation' or even 'uncertainty' (Cook and Seiford, 2009).

However, DEA is a popular approach in the service sectors (e.g., advertisement, finance and banking, education, health care, power distribution, transportation etc.) that are characterised by multiple products and/or less affected by randomness. Growing number of applications in areas such as advertisement efficiency (Luo and Donthu, 2005; Büschken, 2007), finance and banking (Sherman and Gold, 1985; Xiaogang et al., 2005), health care (Hollingsworth et al., 1999; Salinas-Jiménez and Smith, 1996; Hollingsworth, 2003), education (Johnes, 2006; Abbott and Doucouliagos, 2003; Flegg et al., 2004) attest to the popularity of DEA. But DEA is not recommended in the agriculture, particularly in the agricultural frontier applications, because of the nature of randomness in agricultural production process. There are, however, instances in the many subsectors of agriculture where randomness are relatively less in magnitude and/or not so prominent (e.g., poultry farming), and hence DEA can be applied (Coelli, 1995a; Coelli et al., 2005). In reality, DEA has been used in many areas of agriculture such as crop production (Ali and Chaudhry, 1990; Wadud and White, 2000; Coelli et al., 2002; Dhungana et al., 2004; Shafiq and Rehman, 2000; Malana and Malano, 2006), irrigation system (Raju and Kumar, 2006; Speelman et al., 2008), dairy industry (Strokes et al., 2007; Mugera, 2013) etc., although the percentage is very low compared to applications of stochastic frontier analysis in these areas. It is noteworthy here that a considerable percentage of DEA application in the agricultural frontier analysis involves comparisons of results obtained from DEA and alternative approaches (see Hjalmarsson et al., 1996; Bauer et al., 1998; Wadud and White, 2000; Odeck, 2007; Büschken, 2009; Iglesias et al., 2010). However, single approach empirical studies involving DEA in agriculture are also available (e.g., Coelli et al., 2002; Dhungana et al., 2004; Shafiq and Rehman, 2000).

There are empirical studies that applied data envelopment analysis (DEA) in measuring the productive efficiency of rice (e.g., Wadud, 2000; Coelli et al., 2002). The primary goal of these studies relates to comparing different production environments/situations and/or investigating the state of productivity in terms of productive efficiency estimates. Wadud and White (2000) examined the difference between two types of irrigation infrastructures for paddy cultivation in the High Barind region of Bangladesh and Coelli et al., (2002) investigated productive efficiency of dry season Boro rice and wet season Aman rice collecting sample data from three agro-ecological regions of Bangladesh; while Dhungana et al., (2004) attempted to identify the potentials to improve the productivity of rice produced during normal rice growing season in Nepal.

2.3.3 The advent of the stochastic frontier analysis (SFA)

There had long been a need for a model to measure the efficiency of production units in order to make comparisons between production organisations. Much effort was made to this end. After a long wait, a model came into being when M. J. Farrell published his seminal work, titled “The Measurement of Productive Efficiency” in

1957. However, Farrell's model had a number of limitations and it took a couple of decades to improve the model to satisfy both statistical and economic standards. In the continuum process of improving Farrell's seminal model, which is non-parametric by structure, it was developed into a parametric model with a composed error term at one stage. Yet, econometricians were not satisfied at this juncture with this single composed error model, because it is not possible to explain both statistical noise and inefficiency effects with a single error component.

However, the main breakthrough came with the works of Aigner et al., (1977), Meeusen and Van den Broeck (1977), and Battese and Cora (1977), who decomposed the composed error term into two components: the stochastic random error and the technical inefficiency, often called non-negative error term. After this development Farrell's (1957) original model improved to such a robust form that it overcame the major shortcomings of the previous versions of the frontier model, although new features are still being attached to the model, enhancing its analytical capacity. This literature review, however, touches on some of the features and specifications of frontier analysis relevant to the present study. Several important features of frontier analysis, including distributional assumptions of the non-negative error term, estimation of inefficiency effects, choice of functional forms of the econometric model and so on.

2.3.4 The stochastic frontier model

Aigner et al., (1977), Meeusen and Van den Broeck (1977) independently proposed the stochastic frontier model of the form:

$$y_i = f(\boldsymbol{x_i};\boldsymbol{\beta}).\exp(\xi_i - \tau_i)\ \xi_i - \tau_i = \varepsilon_i \text{and } -\infty \leq \xi_i \leq \infty; \tau_i \geq 0 \qquad (2.1)$$

where y_i denotes the output of the i-th farm, *(i=1, 2, 3, . . . n)*

$x_i = (x_{1i}, x_{2i}, \ldots x_{mi}) \geq 0$; a $(1\times m)$ vector of known inputs used in producing output of the i-th farm;

β is a $(m\times1)$ vector of unknown parameters to be estimated

ξ_i, represents symmetric random errors, responsible for measurement error and other factors beyond the control of the production unit and is assumed to be independently and identically distributed as $N \sim (0, \sigma_\xi^2)$;

τ_i, represents asymmetric non-negative random errors, associated with the technical inefficiency of production, which is considered to be under the control of the production unit. This one-sided error term is assumed to be independently and identically distributed such that τ_i is obtained by truncation at zero from below the normal distribution with mean μ and variance σ_τ^2 (i.e., *iid* $N(\mu, \sigma_\tau^2)$). Furthermore, ξ_i and τ_i are assumed to be independent of each other and of the input vector, $\boldsymbol{x_i}$.

However, inclusion of an inefficiency model in the stochastic frontier analysis is well grounded and practical (Kumbhakar et al., 1991; Kalirajan, 1991).There are a number of models proposed by several authors including Kumbhakar et al., (1991), Reifschneider and Stevenson (1991), Huang and Liu (1994) and Battese and Coelli (1995). The Battese and Coelli (1995) model for technical efficiency is very popular because of its capability to assess the effects of inefficiency variables in a consistent manner (see Solis et al., 2009; Singh et al., 2009; Conradie et al., 2006; Karagiannis and Sarris, 2005; Wilson et al., 2001; Sharma and Leung, 2000a; Iinuma et al., 1999; Seyoum et al., 1998; Audibert, 1997). In fact, Battese and Coelli (1995) drew on earlier models proposed by the abovementioned authors to construct this inefficiency model. Hence, the inefficiency component τ_is is assumed to be a function of a set of explanatory variables for the inefficiency effects specified in the stochastic frontier model as

$$\tau_i = z_i\delta + \omega_i = \mu_i + \omega_i \qquad (2.2)$$

where ω is a random variable assumed to be truncated from a normal distribution with a mean of 0 and variance σ^2_ω ; the point of truncation is $-z_i\delta$, and it maintains the condition, $\omega_i \geq -z_i\delta$, in order to ensure the non-negative value of τ_i. More specifically, τ_i can be defined as a non-negative truncation of the distribution with a mean of $-z_i\delta$ and variance, σ_τ^2 i.e., $N \sim (-z_i\delta, \sigma_\tau^2)$;

where

$z_i = (z_{1i}, z_{2i}, \ldots z_{ki}) \geq 0$, a $(1\times k)$ vector of farm- and management-specific inefficiency variables related to the technical inefficiency of the i-th farm; and δ is a $(k\times 1)$ vector of unknown coefficients.

The specifications of the inefficiency model proposed by Huang and Liu (1994) are more complex than the model specified in (2.2). Their model involves additional variables generated by interaction between the input variables (x_i) and the original inefficiency variables (z_i). The inefficiency model of Huang and Liu (1994) can be defined as

$$\tau_i = z_i\delta + z_i^*\delta^* + \omega_i = \mu_i^* + \omega_i \qquad (2.3)$$

where z_i^* is a vector of values obtained by multiplying the input variables with the inefficiency variables, and δ^* is a vector of parameters to be estimated. Therefore, model (2.2) can be termed as a special model which is nested in the model (2.3). If the coefficients in the vector δ^* are zero, the model (2.3) collapses to model (2.2).

The specification of technical inefficiency in (2.2) is close to that proposed by Reifschneider and Stevenson (1991). Indeed, the inefficiency model (2.2) can be considered as an extension of Stevenson's (1980) formulation in that, instead of assuming the mean to be a constant, the model allows it to vary across farms because of the variation in the inefficiency variables and some other factors which are not incorporated into the production function, yet exert an influence on technical inefficiency. Furthermore, this model reduces to the specification proposed by Stevenson (1980) if the first z-variable is equal to one and the coefficients of the rest of the z-variables are zero, meaning $z_i\delta$ becomes a constant. Again, the model (2.2) collapses to Aigner et al., (1977) specified half normal distribution if all elements of δ-vectors are equal to zero, indicating that technical inefficiency effects are not related to z-variables.

In passing, the fundamental difference between a stochastic frontier model and a traditional response model is the non-negative one-sided error term τ_i. However, it was assumed that this error term can take either half-normal or exponential distribution (as proposed by Aigner et al., 1977) or only exponential distribution (as used by Meeusen and Van den Broeck, 1977). Here is the well-known criticism of the SFA that no prior justification is required for selecting a particular distributional specification for the inefficiency term, τ_i. Later, two additional distributional specifications were explored and it was contended that they that can accommodate the non-negative error term. One of these two specifications came from Stevenson (1980), and the other from Green (1990). Stevenson (1980) proposed a more generalised distributional form of truncated normal, while Green (1990) proposed the two parameter gamma distribution for the non-negative error term. According to Coelli (1995b), the extended list of distributions for error term τ_i has attenuated the gravity of the criticism regarding the choice of distributional specification for the inefficiency term, τ_i.

2.3.5 Important features of the SFA model

The stochastic frontier model consists of two major parts—the deterministic part and the stochastic or error part. The stochastic part has two components: the symmetric error and the inefficiency error term. The inefficiency error term itself forms another auxiliary model which is called the inefficiency model. Again, this auxiliary model is divided into deterministic and random parts. However, in the past, the majority of the theoretical stochastic frontier production functions did not explicitly formulate a model for technical inefficiency effects involving appropriate explanatory variables (Battese and Coelli, 1993). Now it is an established fact that inefficiency variables affects the level of output of a production unit and should be counted (Reifschneider and Stevenson, 1991).

Kumbhakar et al., (1991) defined such an inefficiency model as having two components: (i) a deterministic component explained by the vector of observable *qualitative factors,* and (ii) a random component. Similarly, Reifschneider and Stevenson (1991) introduced the inefficiency disturbance as a combination of two types of factors: 'a factor reflecting systematic influences and a random factor'. This definition does not specify the exact nature of the factor responsible for systematic disturbance (the deterministic component); in contrast, the definition of Kumbhakar et al., (1991) restricts the deterministic component to qualitative factors. However, in reality, the deterministic component may comprise both qualitative and quantitative factors. Not only this, some input variables from the stochastic frontier can be included in the inefficiency model as explanatory variables, provided the inefficiency effects are stochastic (Battese and Coelli, 1995). Kumbhakar et al., (1991) introduced the technical inefficiency model explicitly in the context of production function on U.S. dairy farms, while Reifschneider and Stevenson (1991) applied it to electricity generation cost function in the USA. A stochastic frontier function without a model for inefficiency effects is known as an error component model. The Aigner et al., (1977) model is an example of an error component model.

(i) Sensitivity of distributional specifications

As mentioned above, there are four types of distributional specifications that can be assumed against the one sided error term representing inefficiency effects. These are the half-normal, exponential, truncated-normal and gamma distributions. A few empirical works including Green (1990), and Ritter and Simar (1997) have examined the sensitivity of efficiency estimates to distributional assumptions. Green (1990) tested the sensitivity of efficiency estimates and found that the results obtained from gamma distribution discernibly differ from the three other alternative specifications. The author also contended that the gamma model is a better alternative to both half-normal and exponential models. On the contrary, Ritter and Simar (1997) criticised Green's (1990) normal-gamma stochastic frontier model on the grounds of estimation technique and insufficient sample, while the half-normal distribution is criticised for its limitations, in that it is a single-parameter inflexible distribution. Despite these shortcomings, half-normal specification still continues to dominate the empirical studies (see Sharif and Dar, 1996; Kalirajan, 1984; Kalirajan and Shand, 1986; Dawson et al., 1991) with stochastic frontier analysis. The cousin of half-normal distribution, the truncated-normal, a more flexible specification, however, is more popular (see Wadud and White, 2000; Seyoum et al., 1998; Rahman et al., 2009; Tadesse and

Krishnamoorthy, 1997) than the other two specifications, the gamma (see Green 1990 and 2008) and the exponential (see Meeusen and Van den Broeck, 1977; Sharif and Dar, 1996) distributions. Indeed, truncated-normal is the only contender of half-normal in empirical studies of productive efficiency estimation with SFA.

2.4 Alternative Functional Forms of Frontier Models

There are several types of functional forms (e.g., linear, Cobb-Douglas, Quadratic, Normalised quadratic, Translog and Constant elasticity of substitution (CES)), often used to express the production, cost and profit functions. However, in empirical studies preference should be given to those functional forms having the properties of flexibility, linearity in parameters, regularity and parsimony (Coelli et al., 2005, p. 211-212). The principle of parsimony of the functional forms comes first, since it suggests choosing a function that is easily manageable. This particular property is, in fact, the essence of all other properties. Then, there comes the flexibility of the functional models. Thirdly, linearity in the parameters is such that it makes the estimation process easier; while nonlinear functional forms can be estimated using a linear framework if they are amenable to linear transformation. Finally, economic regularity properties (e.g., homogeneity etc.) are often considered for the ease computation of some necessary parameters, such as returns to scale, elasticity of output and so on.

In the literature of estimating productive efficiency with SFA, the most commonly used functional forms are Cobb-Douglas and transcendental logarithm (translog) (see Darku et al., 2013; Bravo-Ureta and Pinheiro, 1993; Battese, 1992). The Cobb-Douglas form is flexible to first-order level, while the translog form has second-order flexibility. So, the first order-flexible forms are preferable to second-order flexibility, as far as the principle of parsimony is concerned. Contrary to this, researchers opt for the second-order functional form, provided other things remain the same. However, second-order flexibility allows estimation of a higher number of parameters, but this causes some econometric problems, including multicollinearity and loss of degrees of freedom. In fact, there is a trade-off between increasing flexibility and soundness of econometric models (Coelli et al., 2005, p. 211). Meanwhile, if the functional form of the model in consideration is nonlinear, it is not a concern insofar as the functional models are subject to logarithmic transformation. It is noteworthy that both the Cobb-Douglas and Transcendental functions are subject to logarithmic transformation.

Functional forms have a discernible impact on estimated parameters as well as efficiency measures; although, there are different opinions on the magnitude of differences between results from one functional form to another. Koop and Smith (1980) made a comparative study involving different functional forms for production technology on steam electric plants. The authors estimated the mean sample efficiencies for Cobb-Douglas and translog functional forms using two different vintage frontier models. Comparing the results across functional specifications, the authors conclude, ". . . that functional specification has a discernible but rather small impact on estimated efficiency. . . ," (Koop and Smith, 1980, p. 1058). Bravo-Ureta and Pinheiro (1993), on the other hand, point out that it would not be wise to generalize Koop and Smith's (1980) conclusion as it was drawn from small samples. The works of Taylor and Shonkwiler (1986), Krishina and Sohota (1991) and Battese and Broca (1997) claim that the functional form has a very small impact on the measurement of efficiency. In fact, the level of significance of the exogenous variables with both the functional forms remains almost the same.

(i) The Cobb-Douglas and the translog functional forms

It is evident from empirical literature dealing with stochastic frontier analysis that the Cobb-Douglas(C-D) model has been used more extensively, despite some of its restrictive properties.Support for this statement can be found in the reviews of the empirical literature prepared by Battese (1992), Bravo-Ureta and Pinheiro (1993), Coelli (1995b) and Darku et al., (2013). Actually, computational convenience is the most attractive feature of the Cobb-Douglas functional form (Coelli, 1995 and Murillo-Zamorano, 2004). The C-D model is also very popular in comparative studies of performance evaluation with production organisations (see Battese and Coelli, 1988; Battese and Teseema, 1993; Bravo-Ureta and Pinheiro, 1993 and 1997; Bravo-Ureta and Evanson, 1994; Coelli and Battese, 1996; Seyoum et al., 1998; Rahman et al., 2012b; Battese et al., 1996. In these studies, technical, as well as cost efficiencies are considered as vital components for a comparison between two or more competing production environments. On the other hand, Sharma (1999) and Sharma and Leung (2002) applied the Cobb-Douglas frontier model instead of the translog frontier model for the efficiency analysis of carp fish production. The authors opined that the translog model was not appropriate for their study due to the presence of a large number of zero values for several input variables because a zero value in the translog model, in turn, generates additional zero values by means of its squared and cross-product terms. As a result, maximum likelihood estimates from the translog form would be poorer than those from the Cobb-Douglas form. O'Neil and Matthews (2001) categorically state that the 'translog specification cannot handle zero values'.

(ii) Choosing a functional form based on key results

It is recommended to check practically which functional form fits the data in consideration. This check can be made in two ways: hypothesis testing, and observing/examining the quality of the estimated parameters. Hypothesis testing is widely used in choosing a functional form; in contrast, choosing a functional form based on the quality of key results is rare. However, the second way is justifiable and is considered as more practical than hypothesis testing. This practice is incongruent with the suggestion offered by Bravo-Ureta and Pinheiro (1993, p. 97) that ". . . an integral part of applied production analysis should be the evaluation of the impact of functional form on the key results of the study". There are empirical studies including Conradie et al., (2006) and Tadesse and Krisnamoorthy, (1997), that upheld Bravo-Ureta and Pinheiro's (1993) suggestions.

2.5 Applications of Productive Efficiency for Performance Evaluation

2.5.1 Pioneering works of performance evaluation in agricultural sector

The body of literature on performance evaluation in terms of productive efficiency estimation with stochastic frontier analysis (SFA) is vast, encompassing a wide variety of firms and organizations belonging to different sectors of modern economies. It is the agricultural sector where SFA has been used most extensively. A large number of empirical studies on performance evaluation in the agricultural sector have been carried out in both developed and developing countries, using stochastic frontier analysis. Battese (1992), Bravo-Ureta and Pinheiro (1993), Coelli (1995b), Thiam et al., (2001) and Bravo-Ureta et al., (2007) provided excellent surveys of empirical studies based on SFA in agriculture. Of these studies, Thiam et al., (2001) and Bravo-Ureta and Pinheiro (1993) presented empirical works on developing countries' agriculture, while others surveyed both developed and developing countries' agriculture. In the broader field of agriculture there are a large number of pioneering works (e.g., Battese and Corra, 1977; Kalirajan, 1984 and 1990; Huang and Bagi, 1984; Kalirajan and Shand, 1986; Battese and Coelli, 1988; Battese and Coelli, 1995; Kumbhakar et al., 1991; Bravo-Ureta and Rieger, 1991; Sharif and Dar, 1996; Wadud and White, 2000). This study reviews a fairly large number of the pioneering works alongside the recent works relevant to the present analysis.

2.5.2 Earlier studies of productive efficiency with frontier analysis

Battese and Corra (1977) pioneered the application of the stochastic frontier analysis in the agricultural sector involving sheep production in the Pastoral Zone of Eastern Australia. In this study, three states belonging to the said zone were compared. The authors used both the deterministic (full-frontier) and stochastic (pseudo-frontier) models along with the traditional average (average-frontier) model and found that SFA frontiers were significantly different from their corresponding deterministic frontiers. Often, early studies of comparative performance evaluation with frontier analysis would employ both full-frontier and pseudo-frontier models. For example, Taylor and Shonkwiler (1986), Eknayake and Jayasuria (1987), Dawson and Lingard (1989), and Bravo-Ureta and Rieger (1990) employed both of these models in analysing the relative positions of competing technologies or management programmes influencing the production environments.

Taylor and Shonkwiler (1986) evaluated the effects of a credit program involving the participants of the credit program vis-a-vis a comparable group of non-participants. For the stochastic frontier model, the average technical efficiencies for participants and non-participants were 0.714 and 0.704 respectively, while those for the deterministic model, the values were 0.185 and 0.059 respectively. These results gave a contradictory conclusion about the impact of the credit programme, and the authors admitted these unexpected estimates from the two alternative approaches. Eknayake and Jayasuria (1987) compared the effects of two sides of an irrigation project, termed as ‘head reach’ and ‘tail reach’. These names were adopted to describe accessibility to irrigation water, where the ‘head reach’ side had better access compared to the ‘tail reach’ side, refereeing two types of production environments for rice cultivation. However, contrasting results from the deterministic and frontier models were found in this study as well.

It is observed from the earlier works that the estimated technical efficiencies of farms from the deterministic model are generally lower than those obtained from stochastic models. This difference may be attributed to the exclusion of some random factors from the deterministic model. Bravo-Ureta and Pinheiro (1993) argue that estimates from the stochastic model are more authentic than those from its deterministic counterpart since it considers statistical noise. The results from earlier studies suggest that it would not be wise to employ a deterministic (non-statistical) approach in empirical studies of performance evaluation. As Kalirajan (1984) and Kalirajan and Shand (1986) report, technical efficiency can be estimated in a number of ways; however, estimations of technical efficiency with reference to the stochastic production frontier outperform other methods since it has the potential to overcome the limitations of others. From the above mentioned studies it is found that Cobb-Douglas type production frontiers were commonly used, while the distribution of non-negative farm effects was confined to either gamma distribution or half-normal.

2.5.3 Productive efficiency with stochastic frontier analysis

As mentioned earlier, the present literature review focuses mainly on empirical studies in the agricultural sector. Again, this section picks up a few subsectors from agriculture that are most relevant to the present work. This would help to concentrate the discussion in a meaningful way. However, this section attempts to synthesise methodological approaches, analytical models and findings of previous studies on productive efficiency with SFA.

(i) Technical efficiency involving paddy production and other crops

Kalirajan (1984) examined the impact of new technology adoption (or green revolution) on agricultural productivity using technical efficiency of paddy production in an agriculturally advanced area. The green revolution was recognised by policy makers as an important way to augment agricultural productivity. However, the study found that there remained ample scope for increasing the yield level, which seems unusual in an agriculturally advanced area. Hence, the author contended that lack of agricultural extension programme is responsible for this unusual result. A similar technology induced rice production environment was investigated by Kalirajan and Shand (1986) in the Kemubu irrigation project in Malaysia. This project provided an environment that allowed for adopting improved rice production technology and the production environment was compared with that outside the project in terms of the technical efficiency of rice farmers. Farmers outside the project had no irrigation facilities and were thus totally dependent on rainfall. In both of the above analyses, the authors employed a translog model, assuming the half-normal distribution of the inefficiency component. However, these studies lack justification for the use of these specifications. Moreover, a limited number of input variables were involved, while no environmental variables were taken into consideration in these comparative analyses. However, from a policy point of view productive efficiency provides valuable information about the existing technology in use (Kalirajan, 1984; Dawson, 1987a and 1990; Dawson and Lingard 1991).

Dawson et al., (1991) attempted to measure farm-specific technical efficiency for rice farms in Central Luzon, the Philippines to see the changes over time comparing his result with the results of some earlier studies in the area. This study is similar to those of Kalirajan (1984) and Kalirajan and Shand (1986), in that it involves a single measure of technical efficiency for each farm with a half-normal distributional assumption for the one-sided error term. On the other hand, Dawson et al., (1991) engaged the Cobb-Douglas functional form, unlike Kalirajan (1984) and Kalirajan and Shand (1986), and justified the use of this form by saying, ". . . serious multicollinearity problems among the cross-product terms led us to prefer a Cobb-Douglas specification" (Dawson et al., 1991, p. 1102). Indeed, it is an established fact that the transcendental logarithmic functional form is more susceptible to multicollinearity problems than the Cobb-Douglas functional form. However, the study found that the yield-gaps between the best- and the average practice farms is not significant and concluded that further technological progress is a must for future increase in rice production.

Sharif and Dar (1996) investigated the sources and patterns of technical efficiency in the cultivation of HYV (high-yielding-variety) and traditional varieties of rice grown in three significantly different seasons (or production environments) in Bangladesh. 'Aus' and 'Aman', are the traditional varieties and grown in the spring and summer seasons respectively, and the HYV, 'Boro', is grown in the winter. However, the study used only four input variables, which seems insufficient as far as the HYV rice is concerned, although these variables are considered the most important ones in rice production. The estimates of the study show that the model is not a good fit as far as t-tests are concerned. Most probably, the estimation process suffers from specification bias in terms of under-fitting the model (see Gujarati and Sangeeta 2007, p. 521, 529). However, the study reveals some interesting and as well as policy oriented findings that higher yield does not necessarily mean a higher level of efficiency; it is the distributional specifications of the one-sided error and not the estimation methods which are sensitive to efficiency level. The study also provides some policy prescriptions relating to productivity enhancement and equitable distribution of income for rural development.

The Study of agricultural productivity in different agro-climatic or ecological zones has special importance from a policy perspective because each of the areas possesses, at least, one unique feature/factor that distinguishes it from others, providing a distinctive production environment which may be good for particular crop(s). Thus, it is very important from a policy point of view to investigate which ecological zone is better for the particular crops, or how congenial a zone is. With similar understandings, Tadesse and Krishnamoorthy (1997) examined the agro-climatic zones of the southern Indian state of Tamil Nadu on the basis of technical efficiency in rice cultivation, using the stochastic production frontier of the Cobb-Douglas functional form. At the same time, the study investigated farm size groups across the ecological zones and their interactions. In this study 'animal power' and 'machine power' have been considered as two separate inputs, but actually they are substitutive factors for tillage. A farmer can apply either or both of these two. Hence, normal practice is to use a single variable for two substitutive inputs through logical conversion; otherwise, it may result in misleading estimates. In fact, the study recorded a counter-intuitive (negative) estimate for animal power. The authors argue here that this is because of overuse of this input. However, the study followed a well-recognised and robust research methodology. Construction and analysis of the pooled model are considered to be a valuable exercise in efficiency literature when it involves comparative analysis; in this regard, this study is a perfect example.

Battese and Tessema (1993) examined the production environments of three areas (villages) selected from three districts representing broad agro-climatic sub-regions in India. This study applied the stochastic production frontier of the Cobb-Douglas functional form with truncated-normal distribution for the non-negative error term using cross-sectional data. Due to variations in agro-climatic conditions, there were remarkable dissimilarities in crops and cropping patterns in the two parts of the study area. So this study used a total value of output around the year as the exogenous variable in the model, instead of converting outputs in a single index (as in Kumbhakar, 1991; Maietta, 2000) or crop-wise estimation of technical efficiency (as in Hadley, 2006).

Using data from the same source of ICRISAT, Coelli and Battese (1996) estimated productive efficiency following the model developed by Battese and Coelli (1995). The basic difference between these two studies (Battese and Tessema, 1993, and Coelli and Battese, 1996) is that, unlike the former, the latter incorporated a model for technical inefficiency effects with the main (error component) stochastic production frontier. However, these two models generated some contradictory findings. For example, Coelli and Battese (1996) model found that the traditional average response function does not represent the agricultural production in the three villages, while Battese and Teseema (1993) found contradictory results in this regard, particularly for the Aurepalle village. That means, the technical inefficiency of production was absent among the farmers of Aurepalle. It looks very unusual as far as a remote village in a developing country is concerned. Again, some findings of Coelli and Battese (1996) are surprising with respect to technical inefficiency effects over time. It is not clear why these contradictory and surprising results came about, although these studies followed robust procedures from a methodological point of view. However, it can be argued that over-manipulation, as well as over-simplification of some input variables and/or a lack of crucial variables in the model, might contribute to these unusual results. For instance, the explanatory variable 'total cost of inputs' was calculated simply by aggregating the costs of several inputs, i.e., the key inputs and ordinary inputs were given equal importance in the estimation process, which is not always a fair means of aggregation. Hence, the total cost of inputs could have been divided into two or more variables according to their relative importance. Furthermore, inclusion of some relevant variables such as rainfall, off-farm income, agricultural extension services, credit programme and so on could have improved the overall evaluation.

Recently Rahman et al., (2009), and Rahman et al., (2012a) studied efficiency and productivity analysis of rice cultivation, covering a wider area for a more representative outcome. Rahman et al., (2009) made a comprehensive study of jasmine rice with a view to understanding the determinants of switching from non-jasmine to jasmine rice involving two types of measurements — the productivity of jasmine rice and the production performance (technical efficiency) of jasmine rice producers. This study selected three provinces of Thailand, viz, Chiang mai, Phitsanulok and Tung GulaRong Hai provinces, which offer different production environments due to varying irrigation facilities, drought conditions, socio-economic conditions and biophysical characteristics. The main focus of this study concentrated on the economics of technology adoption through efficiency analysis. The model used here appears to be a good fit, but it seems lacking some important input variables. Land preparation is generally considered to be an important input variable in rice cultivation but the authors dropped this variable from the model on the grounds that the cost of land preparation per unit of land is the same for most of the farmers, particularly for those who hire tractors. The point is that farmers who use their own tractor certainly spend more time with the same amount of land than those with a hired tractor. Hence, it would have been better if a dummy were included in this regard to control for this phenomenon. Furthermore, inclusion of a soil type dummy would make the model more robust, considering the environmental conditions, particularly with regard to irrigation facilities and drought conditions, since different soil types have varying degrees of moisture retention capacity. One may argue that a provincial dummy would cover this matter, but this may not be true because soil type may vary within a short distance, while a province is a very big area. The study found that, apart from price policy, increasing access to irrigation facilities, availability of fertilizers and investment in secondary education (targeted at farm households) would contribute to breaking the stagnation in switching to Jasmine rice and increase the productivity of Thai rice farmers.

Rahman et al., (2012a) examined the relationship between farm size and technical efficiency with special emphasis on factors contributing to this relationship. The authors employed a fairly large number of input variables, as well as farm-specific inefficiency variables, constructing a comprehensive model, and also surveyed a wider area to collect data from a large number of households with a view to obtaining more representative estimates of the parameters relating to rice production in Bangladesh. Usually, farm household size is divided into three groups in terms of land holding, viz, large, medium and small; however, this study considered four groups, starting from the lowest category, the marginal group, which includes farm households with landholding of less than 50 decimal (where I00 decimal =1 acre). Since land fragmentation is on the rise in Bangladesh (Rahman and Rahman, 2008), this additional grouping of farm household size is justifiable. However, the number of households in each group was selected arbitrarily, not proportionally, which has marred the representativeness of the results. The study found that large farms are more productive followed by medium, small and marginal farms, while fertilizer, manure, insecticide and experience appeared to be the most vital factors in rice production. These studies establish the fact that production environments exert a significant amount of influence on determining the efficiency levels of production units.

In the agriculture sector, a large number of many empirical studies have engaged a stochastic frontier analysis to assess alternative production environments involving a variety of crops other than paddy all over the world. For example, rubber production under different management systems (Vo Hung Son et al., 1993) in Vietnam; wheat production in different regions (Rahman and Hasan, 2011) of Bangladesh; wheat production in different regions (Battese et al., 1993) of Pakistan; hybrid and conventional rice (Xu and Jefrrey, 1998) in China; and grain production (Odeck, 2007) in Norway; maize production (Seyoum et al., 1998) in Ethiopia and (Rahman et al., 2012b) in Bangladesh. On the other hand, in the dairy industry stochastic frontier analysis has a wide range of policy oriented applications, evaluation of production environment (Battese and Coelli, 1988; Ahmad and Bravo-Ureta, 1996) to regional policy (Kumbhakar et al., 1989; Von Baily et al., 1989; Kumbhakar et al., 1991) and evaluation of both production regimes and policy (Dawson, 1987a, 1987b and 1990) through estimation of productive efficiency.

(ii) Technical/cost efficiency of fisheries production

Use of stochastic frontier analysis (SFA) to estimate productive efficiency in the comparative evaluation of different production environments involving fisheries production is rare in the literature of performance evaluation. Although there are general studies of efficiency measures in pisciculture where production environments were not considered as an important issue; simply, productive efficiency in fisheries production has been checked with SFA from regional perspectives (see Singh 2008; Alam et al., 2005; Rahman and Barmon 2012). However, these studies are limited to several species of fish, where carp fish, shrimp and prawn are the dominating varieties. Again, of these three varieties, efficiency studies of carp fish production with SFA overwhelmingly outnumber that of shrimp/prawn production.

A fairly large number of studies including Singh et al., (2009), Singh (2008), Alam et al., (2005), Sharma (1999) Iinuma et al., (1999), Sharma and Leung (1999, 2000a and

2000b), investigated technical efficiency of carp production applying SAF; meanwhile, using the same analytical tool few studies e.g., Begum et al., (2013), Rahman et al., (2011), Rahman and Barmon (2012) studied efficiency of shrimp/prawn production. Most of these studies involved production frontiers in estimating technical efficiency. On the other hand, the works of Singh (2008) and Alam et al., (2005) are exceptional to the above works in one way or another. Singh (2008) estimated both technical and economic efficiencies using the Cobb-Douglas functional form, while Alam et al., (2005) used a more flexible translog form involving a technical inefficiency model.

Turning to the methodological aspects of efficiency estimation in fisheries production, efficiency studies in aquaculture usually involve either carp, shrimp or prawn individually; a combination of two e.g., carp-shrimp or carp-prawn or shrimp-prawn mixtures are rare. However, there are no or a few studies that have involved these three species together (carp-prawn-shrimp), to the best of the researcher's knowledge. In fact, a combination of the three requires a unique agro-hydrological environment, having access to both brackish and fresh waters, and can regulate the supply of both types of water as required. The tidal river basin management (TRM) system offers such a unique environment that can provide the above production environment. This study pursues an analysis of such a production process. It is expected that the analysis in the present study will provide some additional information in the literature of performance evaluation with reference to fisheries production.

2.6 Estimating Productive Efficiency: Some Useful Approaches

2.6.1 The case of cost efficiency

The vast majority of empirical works belonging to performance evaluation literature applied production frontier approach to estimate technical efficiency. This is because of the fact that most of the production organisations satisfy Zellner et al., (1966) assumption of expected profit maximization. Meanwhile, a considerable number of empirical works in the literature of performance evaluation engaged the cost frontier approach to estimate cost/economic efficiency. Estimation of cost frontiers has two distinctive approaches: the single equation approach (SEA) and cost system approach (CSA) (Bauer, 1990). The cost system approach of estimating cost efficiency is often used in order to obtain separate estimates of technical and allocative efficiencies. In contrast, the single equation approach directly calculates the economic efficiency and this is not separable into technical and allocative efficiency. However, the cost system approach has some serious drawbacks. It is not possible to incorporate the farm- and management-specific variables into the cost system approach (see Bravo-Ureta and Reger 1991). Most importantly, the success of this approach is very much related to the quality of data, in that observation of input and prices of inputs must be non-zero; otherwise, the system would provide inconsistent estimates (see Bauer, 1990; Rahman, 2002; Wadud, 2002).

However, application of a specific approach (single equation and cost systems) depends mostly on its adjustment with the situation. In many empirical works (e.g., Farsi and Filippini, 2009; Ali et al., 1996; Parikh et al., 1995; Cebenoyan et al., 1993; Reifschneider and Stevenson, 1991; Ali and Flinn, 1989; Stevenson, 1980), single equation cost functions are engaged in performance evaluation of the production units;while there are empirical studies, including Bhattacharyya et al., (1995), Bravo-Ureta and Evenson (1994), Barvo-Ureta and Pinheiro (1997), Kumbhakar (1987, 1988), Bravo-Ureta and Reiger (1991), where the cost systems are used in evaluating the performance of production organisations.

There are situations that justify the single equation approach over the cost system approach. Rahman et al., (2012b) applied single equation method with Cobb-Douglas functional form in an attempt to compare two growing seasons (winter vs. summer) of maize in Bangladesh. In this study, the authors considered a wider range of variables that made the study more comprehensive. Hesmati and Kumbhakar (1997) used the single equation method in estimating cost efficiency in the provision of education. Hiebert (2002) attempted to evaluate two types of technologies involving electricity generation, namely, coal-based electricity generation plants and natural-gas-based plants with a single equation cost frontier. Unlike Hesmati and Kumbhakar (1997), the author used a translog functional form with a single model following Battese and Coelli's (1995) specifications. Hesmati and Kumbhakar (1997) developed different models based on the adjustment of output and treatment of inefficiency variables which allowed for cross-checking the efficiency of the production units. In fact, developing a variant model within the range of data is good practice as it gives wider scope to explore a well-fitting model. For example, formulation of a pooled model provides an opportunity to cross-check the efficiency of production units as well.

2.6.2 Pooled model for estimating productive efficiency

The case of the pooled model arises when production activities are spread over different situations e.g., contrasting production environments, different years, regions, climatic conditions etc. Hence, development of a pooled model gives a better understanding of efficiency measures, since it estimates the parameters creating a level playing field for all production units involved. A pooled model is developed by combining the individual models and putting a dummy for each individual (sub-sample) model. Again, there is scope to have some adjustments with the explanatory as well as dummy variables, which ultimately lead to formulating a restricted pooled model. However, the interpretations of the dummy variables may differ since they can represent diverse situations. For example, Conradie et al., (2006) used dummies to allow for regional and time variations in separate pooled models while Kumbhakar (1994) used regional dummies to capture the differential effects of soil, terrain and weather.

Battese and Coelli (1988) introduced the application of a pooled model in the frontier analysis to predict firm-level technical efficiencies perhaps for the first time. In the study of performance evaluation that compared dairy farms in New South Wales and Victoria, the authors employed an error component model, i.e., a stochastic frontier without an inefficiency effect model. Drawing on Battese and Coelli (1988), Conradie et al., (2006) developed a number of pooled models in their study of grape farms in South Africa. The authors included data from five individual samples covering two panels of Robertson and Worcester wine grape farms (over the years 2003 and 2004) and table grape farms in De Doorns for the year 2004. The basic difference between these two pooled models is that Conradie et al., (2006) developed the pooled model involving a stochastic frontier model with the technical inefficiency effect, while the former without the technical inefficiency effect. Moreover, Conradie et al., (2006) developed a number of pooled models based not only on the spatial study but also on temporal considerations. The idea of developing a pooled model is that it is an effective way of comparing different production situations and are applied by many other authors, including Kalirajan and Shand (1986), Kumbhakar et al., (1989), Tadesse and Krishnamoorthy (1997), Rahman et al., (2009) van der Vlist et al., (2007).

2.7 Performance Evaluation Using Yardsticks of Productivity

There is scope to go beyond the estimation of productive efficiency in performance evaluation of production environment in agriculture (Herdt and Mandac, 1981). 'Yield-gap' and 'cost-gap' based respectively on production frontier and cost frontier are very useful measures here. These measures can be termed as basic yardsticks of productivity. Apart from these two measurements, there are some other variant measurements that can be applied effectively in this connection.

2.7.1 Understanding yield-gap and related concepts

Yield-gap is an important concept in the agricultural sector and has emerged as a reliable yardstick in the literature of performance evaluation. Understanding the yield gap helps acquiring information about a number of important issues, e.g., projection of future crop yields for different regions (Pingali and Heisey, 2001), efforts to be taken to increase output level or minimise the yield-gap (Lobell et al., 2009), differentiating various production organisations and so on. A small yield-gap indicates that growth rates are likely to be sluggish in the future; information about the factors responsible for yield gap provides an idea of the cost of increasing productivity further.

Yield-gap refers to the mathematical difference between yield potential and average farmers' yield (Lobell et al., 2009; van Ittesum et al., 2013). Yield potential here is an important concept which indicates the highest possible level of output. The yield level grown with a sufficient supply of nutrients and water, and all the stresses including pests, diseases and weeds are effectively controlled in an adapted environment, refers to yield potential (Evans, 1993, p. 292). Cassman (1999, p. 5954) criticises this definition, terming it 'straightforward'. He argues that it is not possible to eliminate all biotic and abiotic stresses, so measurement of yield potential for actual field conditions is difficult. Since yield potential refers to the maximum possible output in a specific production environment, it is very likely that it would vary with different production environments. Indeed, different production environments offer different yield potential. In reality, yield potential is not a quantity but a concept, which makes its estimation both complicated and challenging (Cassman, 1999, p. 5954). The concept of yield-gap can be qualified as simple or complex, depending on the definition and measurement of yield potential, since it can be defined and assessed from different perspectives. According to Lobell et al., (2009), this is the reason behind the lack of consistency in yield-gap analysis in the literature. However, the measurement of potential yield (or yield potential) can be done in several ways for the assessment of yield-gap (Herdt and Mandac, 1981); then it is a challenge to select an appropriate yield potential. Most empirical yield-gap studies apply only a single definition of yield potential, while it is recommended to use multiple methods of measuring potential yield in the comparative study of yield-gap (Lobell et al., 2009; Aggarwal et al., 2008).

There are also different types of yield-gap, depending on the characteristics/features of the production environment itself. So, the type of a yield-gap relates to how a production environment has been defined and/or how the potential yield has been conceptualised etc. Herdt and Mandac (1981) introduced two well-known types of yield-gap which are often used in empirical studies. The first one is calculated as the difference between the maximum yields at the experimental station and the maximum yield under farmers' conditions, whilst the second one is the difference between the maximum possible yield under farmers' conditions and the farmers' observed yield. The first type may be useful for testing input varieties (e.g., seed types, fertilizer quality and so on) or assessing the impact of agrochemical technologies in different conditions, whereas the second type applies to measuring the relative performance of different production units within specific conditions.

2.7.2 Yield-gap and performance of a production environment

A production environment in agriculture is judged primarily by the quality and quantity of the components/factors it offers in the production process and how much congenial it is for other external factors of production. Putting differently, a production environment influences the efficacy of the factors of production involved in the production process which in turn determine the level of output and then yield-gap. Thus, evaluation of a production environment in terms of yield-gap reflects the combined influence of the input factors belonging to the production environment. Lobell et al., (2009) mentioned a varied list of biophysical factors that generally affect crop growth and yields in farmers' conditions, and eventually the yield-gap. Among the biophysical factors, the important common factors are soil conditions (such as salinity, alkalinity, acidity, iron, aluminium, boron toxicities, compaction, and others) water stress, flooding, fertilizers (e.g., nitrogen, phosphorus, potassium, zinc etc.) and weed pressure. Any combination or even one of these factors can bring about a change in an existing production environment which is enough to make a change in yield-gap. Therefore, measurement of yield-gaps with different production environments indicates their relative performance/contribution to agricultural productivity. A considerable number of empirical works employed yield-gap to this end, however, with diverse types of objectives such as examination of organic agriculture and conventional agriculture (de Ponti et al., 2012; Seufert, 2012; Stanhill, 1990; Lotter, 2003; Goulding et al., 2009); inquiring into the nutrient and water stress conditions (Boling et al., 2011); investigating rain-fed and irrigated farming (Yang et al., 2004; Aggarwal et al., 2008) and so on.

2.8 Summary and Conclusions

The concept of productive efficiency has wider applications in the literature of performance evaluation. In the agricultural sector, the performance of different production environments/organisations is often evaluated through productive efficiency based on the productivity of the farms involved. Hence, technical and cost efficiencies—the two main types of productive efficiency—are predominantly used. There are several approaches to estimating these efficiencies; however, stochastic frontier analysis (SFA) is considered to be the most appropriate, since it is fully consistent with the neoclassical theory of production.

Stochastic frontier analysis (SFA) has emerged over time as a powerful and flexible analytical tool in the arena of performance evaluation. It has some special qualities/features that help promote its widespread use in diverse sectors to compare competing technologies/interventions/programmes through estimating productive efficiency of the production units thereof. Indeed, estimates of productive efficiency with SFA carry significant importance in a policy context (see Rahman et al., 2009; Reinhard, 1999; Kumbhakar et al., 1989; Taylor and Shonkwiler, 1986; Dawson and Lingard, 1989; Dawson et al., 1991; Kalirajan, 1984; Seyoum et al., 1998; Xu and Jefrrey, 1998). In addition to productive efficiency, yield-gap, cost-gap and related measures can also be used as alternative means of comparing different competing technologies or interventions or programmes through estimating the productivity of the production units thereof.

However, there are challenges to estimating productive efficiency with stochastic frontier analysis including choice of the appropriate specification of the one-sided error term that represents the inefficiency effects, the functional form of the frontier model and the types of efficiency to be estimated. Meanwhile, the main challenge to evaluate productivity performance with yardsticks of productivity is the measurement of the yardsticks themselves because there are alternative methods for measuring the same yardstick. Hence, it is recommended to use multiple methods to allow for a comparison which provides an opportunity to cross-check and then choose the appropriate one.

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CHAPTER THREE
THEORETICAL FRAMEWORK AND METHODOLOGY

Chapter Structure

Chapter THREE

Theoretical Framework and Methodology

Objectives and Organisation of the Chapter

The aim of this chapter is to illustrate the theoretical underpinnings of the methodologies used in estimating productive efficiency for performance evaluation and clarify the key concepts in this connection. The first section of this chapter highlights the importance of productive efficiency and stochastic frontier analysis (SFA) in performance evaluation. Providing the theoretical basis of productive efficiency, the second section explains the basic concepts about the frontier production with simplified examples. Then it illustrates the development stages of frontier model and its estimation techniques. The third and fourth sections describe the features of stochastic frontier models and the procedures for estimating parameters and predicting efficiency scores. Section five exclusively explains the methodological issues related to cost frontier analysis. Adjustment of zero observations, functional forms of frontier models and yardsticks of productivity are described in section six, seven and eight respectively. Section nine and ten discuss the rules of hypotheses testing and sampling techniques of data collection respectively, while the last section presents the summary and conclusions.

3.1 Introduction

This chapter discusses methodological issues related to productive efficiency estimation and provides theoretical underpinning of the methods used for the estimation. Productive efficiency is often used as a means of performance evaluation of an intervention that affects production environment (Eknayake and Jayasuria, 1987; Kalirajan and Shand, 1986; Seyoum et al., 1998; Speelman et al., 2008). Two competing and contrasting flood control and drainage management (FCDM) systems, namely, the 'silt-dredging and regulative-drainage management (SRM)' and the 'tidal river-basin management (TRM)' were implemented in the Southwest coastal zone of Bangladesh as a safeguard for agricultural production. However, the primary goal of this study is to evaluate these two competing interventions from the perspective of agricultural productivity. It is evident from the review of literature that performance of the management interventions are evaluated by estimating the productive efficiency of the production units associated with the interventions (see also Liu, 2010 and Reinhard, 1999). Førsund et al., (1980) report that it is appropriate to employ either a production frontier (technical efficiency) or a cost frontier (cost efficiency) in evaluating the performance of production units/organisations. Meanwhile, Kalirajan and Shand (1999) put more emphasis on production frontier. The present study, however, has taken both technical and cost efficiencies into account, considering the behavioural assumptions relating to the farming practices for an overall evaluation of the two competing flood management and drainage systems. In addition to two the aforementioned of productive efficiency estimates (i.e., technical and cost), this study employs several yardsticks of productivity (e.g., yield-gap, cost-gap, and input usage patterns etc.), for evaluating the two FCDM systems. From the review of empirical works on comparative performance evaluation, it appears that stochastic frontier analysis (SFA) outperforms other alternative methods of productive efficiency estimation. The present chapter, however, illustrates the theoretical underpinnings of the frontier analysis, the principal analytical approach, along with other methods for assessing the productive performance of the FCDM systems.

3.2 Theoretical Underpinnings of Productive Efficiency and Frontier Analysis

3.2.1 Theory of production and productive efficiency

Neo-classical theory of production forms the theoretical basis of the analytical framework of this study. In the theory of production, productive efficiency is an important concept and it continues to receive increasing attention in the literature of performance evaluation. Productive efficiency is basically an output-input ratio and it differs from one production unit to another for a number of reasons. Different production units experience different production relationships (or output-input ratios) due to the impact of varying states of technology or random disturbances (associated with different interventions); in some cases, existing technology is exploited more efficiently in a particular production environment (Shapiro and Muller, 1977, cited in Herdt and Mandac, 1981, p. 376). In reality, combinations of all or some of these factors lead to different production units eventually appearing with different productive efficiency ratings.

As mentioned earlier that an intervention can be assessed by the productive efficiency of a production unit operating within the production environment created by the intervention itself. The logic here is that the input-output relationship of a production unit is mostly determined by the associated production environment, while the production environment is caused by the intervention. Thus, the performance of a production unit can eventually be attributed to the intervention itself. By the same token, the performance of all farms in a case study area (in terms of productive efficiency or yardstick of productivity) can be attributed to the intervention as a whole. This attribution principle is widely practiced in assessing comparative performance of different types of interventions in production economics. Usually productive efficiency of producing a product under different interventions is used to compare them in terms of their relative contribution to productivity. This is an established approach by which a wide variety of interventions (e.g., irrigation project, management systems, policy measures, programmes and so on) are assessed (see Eknayake and Jayasuria 1987; Coelli et al., 2005, p. 1; Battese and Coelli 1996; Kalirajan 1981,1982 and 1984; Kumbhakar et al., 1989; Von Baily et al., 1989). Likewise, the present study evaluates the two competing flood control and drainage management (FCDM) systems, the SRM and the TRM, using the productive efficiency of the farms operating under them.

The literature on comparative performance evaluation provides several approaches to determining the relative positions of the interventions in terms of productive efficiency or performance of production units. Of these, the frontier production function method proposed by Aigner et al., (1977) and Meeusen and Van den Broeck (1977) occupies a broader space in the literature because of its sound and robust theoretical basis. Kalirajan and Shand (1986) plainly explain the concept of frontier production with simple examples, albeit following an economically and statistically justified way of technical transformation of inputs and outputs. These are:

Case- 1: one input - one output under constant returns to scale

The ratio of output to input can be calculated for each of the farms under consideration and the highest figure is the frontier production (FP).

Case- 2: one input - one output under variable returns to scale

The calculated output-input ratios in a specified functional relationship are plotted in a scattered diagram and the smooth curve joining the highest figures represents the frontier production.

Case- 3: Two input - one output under constant returns to scale

Industry-A is being operated in a given state of technology, employing two-inputs, *x* and *z,* to produce a unit of output, *y*. The ratio of input to output is plotted in a scatter diagram, where each point represents the combination of *x* and *z* inputs applied to produce a single unit of *y*. The curve joining the lowest point represents the frontier production; in fact, it is the efficient isoquant.

Case- 4: Two input - one output under variable returns to scale

Case-4 is the same as case-3, except for specifying a functional form. Hence, the smooth curve represents the frontier production.

From the above description, it can be deduced that each production unit has its own production function/frontier. In fact, different production units (or producers) experience different production relationships because of factors beyond their control. Meanwhile, environmental conditions, which may be different for each production unit, in part contribute to determining the frontier level (maximum level) of output for each bundle of inputs. Consequently, the measure of technical efficiency for each production unit (or producer) is different. Therefore, unique production function applies to each production unit if environmental factors are involved (Herdt and Mandac, 1981, p. 380).

(i) Frontier production and cost: The basic concepts

The standard exercise in evaluating the performance of production organisations/units involves empirical estimation of production function and/or cost function. Interpretation of these functions or production activities differs with the estimation methods; while the most commonly used estimation methods take either the 'average' or 'frontier' concept in interpreting the production activities (Førsund et al., 1980, p. 19). However, it is very important to choose which type of interpretation or estimation technique is appropriate for a specific analysis. Hence, the purpose of the analysis and the theoretical basis of the function to be estimated are required to be considered from the outset. The theoretical definition of a production function postulates that farms produce a maximum level of output from given input bundles and technology, while a cost function expresses the minimum cost of producing a fixed amount of output, given input prices and technology (Førsund et al., 1980). A production function refers to 'maximum output', while the cost function relates to 'minimum cost'; in contrast, the least squares method provides average estimates of these functions. Most empirical studies in the past used the least square methods because of the unavailability of an alternative or better approach. As Aigner et al., (1977, p. 21) state,

> "..... for almost as long, econometricians have been estimating average production functions. It has only been since the pioneering work of Farrell (1957) that serious consideration has been given to the possibility of estimating so-called frontier production functions, in an effort to bridge the gap between theory and empirical work".

Until the introduction of the frontier estimation approach, econometricians implemented the textbook paradigm in estimating production, cost and profit functions, assuming producers achieved the goal of maximality or minimality. Hence, the least squares technique or its variants were employed, assuming the error term was systematically distributed with zero means and the only source of variation from the estimated function was the statistical noise (Kumbhakar and Lovell, 2000, p. 2). Not all producers under a production environment are successful in achieving the goal of maximality or minimality. More specifically, in the case of production, not all producers are technically efficient; for cost minimisation, not all agents (producers) are cost efficient and for profit maximization not all entrepreneurs (producers) are profit efficient. This failure of the producers (at least some of them) to attain optimal conditions indicates inconsistency with the theoretical concept of production economics, suggesting the adoption of an alternative approach to estimating production, cost and profit functions. It is desirable here to deal with these functions using the frontier concept rather than the average concept. In the words of Fried et al., (2008, p. 33),

> "The economic theory of production is based on production frontiers and value duals as cost, revenue and profit frontiers, and on envelope properties yielding cost minimizing input demands, revenue maximizing output supplies, and profit maximizing output supplies and input demands".

A frontier concept sets a limit to the range of possible outcomes; this limiting state is taken as an 'ideal' and this 'ideal' is considered as the efficient state (Førsund et al., 1980; Green, 1999). The 'ideal' for a production function is the maximum level of output for a given set of input bundle, while for a cost function it is the minimum cost to produce a given amount of output. In both of the cases, it is assumed that the state of technology is given. The locus of all efficient output points, with respect to the different sets of inputs, constructs the production frontier. Similarly, the locus of all efficient cost points, with respect to different amount of outputs, constructs the cost frontier. Production activity on the production frontier is termed *technically efficient*, while others below the production frontier are termed *technically inefficient*. On the other hand, production activities on the cost frontier are termed *cost efficient*, while others above the cost frontier are termed *cost inefficient*. The frontier value refers to the best practice value among the production units. The deviation between the maximum (or minimum) possible value and the observed values regarding output (or cost) is termed 'technical (or cost) inefficiency of the production unit'. The measure of technical inefficiency of a farm is defined by the extent to which it lies below its production frontier; likewise, cost inefficiency is determined by the extent to which it lies above its cost frontier (Førsund et al., 1980, p.5).

In passing, Coelli (1995) encapsulates the facts of the average (e.g., ordinary least squares) functions and frontier functions by saying that in frontier estimation, individual farms can be compared in terms of their respective performance, and can be measured in terms of the best performing farm since each individual farm has a distinctive position in the industry. In contrast, the ordinary least square method provides the average performance level of the firms in the industry.

3.2.2 Frontier analysis: From a trivial to a sophisticated model

In order to have an in-depth understanding of an analytical tool, it is better to begin with its starting point. This section highlights the development stages of frontier analysis.

> "If econometric analysis is to be brought to bear on the investigation of the structure of economic frontiers, and on the measurement of efficiency relative to these frontiers, then conventional econometric techniques require modification. The modifications that have been developed, improved and implemented in the last three decades run the gamut from trivial to sophisticated" (Fried et al., 2008, p.33-34).

Passing through a number of stages, the frontier approach has taken up a number of sophisticated features thereby builds up its analytical capability with flexibility. These stages can be classified into three-pair categories: first, statistical or non-statistical, based on the relationship between observed output and the frontier output; secondly, parametric or non-parametric, based on input functions; lastly, each frontier model itself is either deterministic or stochastic, based on the qualification/specification of the error term(s) (Førsund et al., 1980, p. 8). From these pair categories, several possible combinations can emerge. However, all of these combinations are not prominent in the literature of efficiency estimation. A few of them are very important because of their noteworthy contributions to the subsequent development stages of techniques of efficiency measurement.

These are:

a) Deterministic non-parametric frontiers
b) Deterministic parametric frontiers
c) Deterministic statistical frontiers
d) Stochastic frontiers

Discussion of frontiers and efficiency measurement is assumed to be incomplete without the seminal work of Farrell (1957); in fact, it deserves to be addressed at the outset of the discussion. However, according to Farrell's model, a firm's efficiency is viewed from two distinctive perspectives: technical and allocative; these two forms of efficiency make up a combined form which is termed 'economic efficiency'. Technical efficiency relates to the ability of a firm to achieve maximum possible output with given input bundles, while allocative efficiency refers to the ability to utilise an optimal combination of given inputs; economic efficiency, on the other hand, is the multiplication of these two efficiencies. The original terms (i.e. the terms used by Farrell, 1957) to indicate different types of efficiency are different from those that are most commonly used. For example, Farrell used the terms *price efficiency* to mean allocative efficiency, and *overall efficiency* to mean 'economic efficiency'; furthermore, *economic efficiency* is often called '*cost efficiency'* (Coelli et al., 2005, p. 53). The term 'technical efficiency' remains the same, however.

a) Deterministic non-parametric frontier

Farrell (1957) illustrated the measurement of efficiency by giving a general notion of efficiency thus: '.......efficiency of a firm means its success in producing as large as possible an output from a given set of inputs and assuming constant returns to scale. Farrell's model provides an overall computational framework of both 'technical' and 'allocative' efficiencies. Although it is possible to estimate efficiency from both input and output perspectives, Farrell's original idea was presented in input/input space with the focus on input minimisation. This approach is termed the 'input-oriented measure'. The following section describes the input-oriented approach to efficiency measurement.

(i) Input-oriented efficiency measure

Farrell's description of efficiency measurement has been depicted in different ways by researchers. For example, Kopp and Diewert (1982) presented Farrell's efficiency measure in a way that relates to decomposing cost function. The present section, however, illustrates the input-oriented measurement drawing on Kopp and Diewert's (1982) and Coelli (1995b). Consider a situation where the production function takes the form $y = f(x_1, x_2)$, meaning the farm employs two inputs, x_1 and x_2, to produce a single output *y.* It is assumed that the efficient production technology is known and it follows constant returns to scale (CRTS). Thus, the production frontier can be written as $1 = f(x_1/y, x_2/y)$, meaning the frontier technology is characterised by the unit isoquant (Førsund et al., 1980).

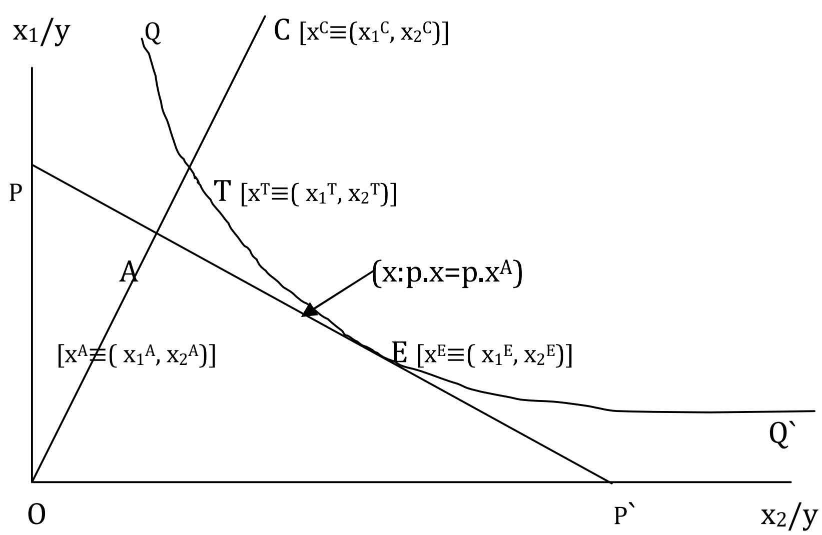

Figure 3.1: Farrell-type Efficiency Measurement

In diagram 3.1, different production activities are represented by C, T and E points and QQ′ is the efficient unit isoquant. Suppose the farm is using input combination, (x_{01}, x_{02}) to produce y_0 with production activities represented by C. Of these three production activities, C is inefficient and it cannot be below QQ` by definition (see Førsund et al., 1980). The point T is obtained by the intersection of the ray OC with the efficient isoquant QQ′, and T represents an efficient production activity using the two factors in the same proportion as used by C. The distance TC could be taken as the extent of technical inefficiency of the farm as this is the amount by which the two inputs could be reduced proportionally without reducing the output y_0. This measurement can be expressed in unitary or percentage terms, converting it to the ratio of TC/OC. Hence, the farm can achieve a technically efficient level of production by reducing, the inputs at TC/OC percent.

In general, the technical efficiency (TE) of a farm operating at point C is measured by the ratio OT/OC;

i.e., TE = OT/OC = 1 – (TC/OC) = 1- technical inefficiency $(0 \leq TE \leq 1)$ (3.1)

If the farm operates at point T, located on the frontier isoquant, it is 100 percent technically efficient; hence, TE = 1.

The allocative efficiency (AE) of the farm can be measured using the distance between A and T, which is expressed by the ratio OA/OT. i.e.,

$AE = OA/OT \qquad (0 \leq AE \leq 1)$ (3.2)

Measurement of allocative efficiency essentially involves input prices. Given competitive factor markets and the relative prices p_1 and p_2, the isocost line is PP′. The isocost line intersects the ray OC at point A and touches the isoquant at point E. Meanwhile, production activity is fully technically efficient at both of the points T and E; however, only point E is optimal, because the cost of production at point E is less than that at point T. Cost at point E is less than cost at T by a fraction of OA/OT (here OA/OT< 1) (Farrell, 1957, p. 255).

When a farm achieves both technical and allocative efficiency, this state is called *economic efficiency;* Farrell termed it as *overall efficiency* or *perfect efficiency* (see Farrell, 1957, p. 255). In diagram 3.1, the cost at point A is the same as the cost at point E, since both of the points are on the same isocost line. Furthermore, the farm operating at T can reduce the proportion of inputs to the (proportionate) level at E, thereby reducing the cost by a factor of OA/OT, given that prices remain the same. The farm can achieve this improvement maintaining the technically efficient status.

Measure of economic efficiency, therefore, can be expressed as

EE = OA/OC (3.3)

Again, this measure is the product of technical efficiency and allocative efficiency, thus:

$EE = TE * AE = OT/OC. OA/OT = OA/OC \qquad (0 \leq EE \leq 1)$ (3.4)

So, economic inefficiency = 1 – EE = 1- OA/OC = AC/OC (3.5)

These assessments indicate that the farm can ward off extra cost which is proportionate to a distance of AC by producing on an economically efficient isoquant.

The above measurement of efficiency is based on an efficient isoquant, which is constructed with reference to a sample of probably inefficient observations since an efficient isoquant is not observable. This measurement technique applies a linear programming method, using the free disposal convex hull of the observed input-output ratios; in this sense, Farrell's approach is termed as non-parametric. There is no need to impose any functional form on the data set and this is the main advantage of Farrell's approach. However, it suffers from serious problems in terms of scale technology and computation of the frontier. In addition, the approach is restricted to constant returns to scale and it is very difficult to extend it to a non-constant returns to scale. Therefore, the frontier is calculated from a leading subset of sample observations, making the approach susceptible to extreme observations and errors in measurement (Førsund et al., 1980). However, regarding the other models listed in (b) to (d), the development issues of these models were mostly associated with the structure of error component(s) and then difficulty levels in estimating the models.

b) Deterministic parametric frontiers

The deterministic parametric frontier model was developed as an afterthought of M. J. Farrell (1957). This approach overcomes some of the fundamental limitations of the deterministic non-parametric model by introducing a parametric convex hull of the observed input-output ratio and accommodating non-constant returns to scale. Here, the recommended functional form was Cobb-Douglas[1]. However, Farrell himself did not modify his model by acting upon his own suggestions. It was the empirical work of Aigner and Chu (1968) which reflected Farrell's suggestions for the first time. Following Farrell's suggestions, the authors used a homogenous Cobb-Douglas production frontier with the specification that all observations should be on or beneath the frontier.

[1]Førsund et al., (1980) justifiably argue that at that time there were few functional forms available, so there was limited scope to involve more functional forms.

The Aigner and Chu (1968) model is expressed as

$$y_i = f(x_i ; \beta_i) \exp(-\varepsilon_i) \quad ... (\varepsilon_i \geq 0 \text{ and } i = 1, 2, 3, ...n) \qquad (3.6)$$

Where y_i = observed output of the i-th production unit

$\mathbf{x}_i$ = vector of input level for i-th farm; β_i = vector of unknown parameters, and

ε_i = the one-sided error term representing technical inefficiency.

The production frontier (3.6) is deterministic to the extent that y_i is bounded from above by the non-stochastic amount of output exp ($\mathbf{x}_i'\beta$). The distinct feature of this type of frontier is that statistical noise and measurement errors are not taken into account, so all deviations from the frontier are attributed to technical inefficiency (ε_i); thus, the inequality condition here appears as $y_i \leq \exp(\mathbf{x}_i'\beta)$. Aigner and Chu (1968) estimated the parameter vector β using a linear programming technique, in which the sum of the absolute values of residuals is minimised, subject to the constraint that the residual value of $\varepsilon_i \leq 0$. Thus,

$$\sum_{i=n} | y_i - f(x_i ; \beta_i)| \qquad (3.7)$$

subject to $y_i \leq f(x_i ; \beta_i)$

Alternatively, the authors proposed a quadratic programming model in which the sum squared residuals are minimised, subject to the constraint that the residual value of $\varepsilon_i \leq 0$. Thus,

$$\sum_{i=n} | y_i - f(x_i ; \beta_i)|^2 \qquad (3.8)$$

subject to $y_i \leq f(x_i ; \beta_i)$

(for both cases, the residual $\varepsilon_i = | y_i - f(x_i ; \beta_i)|$ and $f(x_i ; \beta_i)$ is linear in β)

Between these two alternative methods, the authors regarded that linear programming estimators are better than the estimators from quadratic programming.

However, this model has two serious problems in terms of sensitivity to outliers and lack of statistical properties. Like the non-parametric approach, in this case also, the frontier is estimated on the basis of a subset of sample data and, thus, it is very sensitive to outliers. Nonetheless, to overcome these problems, Aigner and Chu (1968) suggested another method that involves arbitrary selection of a small portion of observations to be deleted, with a view to rectifying the sample data. This method is known as the *probabilistic frontier*[2] approach. Later, Timmer (1971) and Dugger (1974) as reported by Aigner et al., (1977, p. 22) implemented this suggestion in their empirical works. Since this arbitrariness lacks economic and statistical justification, the probabilistic approach became unacceptable to the frontier literature and, thus, the approach could go no further.

The second issue is that this approach relies on a mathematical programming procedure to obtain the estimates; accordingly, the estimates are not amenable to inferential statistics.

However, under deterministic parametric frontiers, no distributional assumptions are made about the error term, resulting in non-statistical estimates. This is why inferential statistics are not applicable to the estimates of deterministic parametric frontiers. These shortcomings were addressed in the later stage of development.

[2]The so-called probabilistic frontier approach involves several steps to complete the estimation process. First, the frontier is estimated, using all the sample observations; secondly, an arbitrary percentage of observations which are very close to the frontier are deleted and the model is re-estimated using the reduced samples (Coelli et al., 2005, p. 242). These actions are considered to be useful if the rate of change of the 'estimates' diminishes rapidly with respect to the succeeding deletions of observations (Førsund et al., 1980).

c) Deterministic statistical frontier

At this stage, the development of the frontier model mostly involved structural improvement of the error term and implementation techniques. One of the major problems of the deterministic parametric frontiers (as mentioned above) is the non-statistical estimates since there was no distributional assumption about the error term. In the present deterministic statistical frontier model, that problem is removed by making the assumption about the error term, ε_i, in association with the explanatory variables, x_i that the observations on ε_i are independently and identically distributed, and that x_is are independent of ε_i.

Afriat (1972) was the pioneer who explicitly developed this model, assuming gamma distribution of the inefficiency term ε_i. He was followed by Richmond (1974), who made the same distributional assumption but used a different implementation technique. Afriat (1972) used the maximum likelihood (ML) method of estimation, whilst Richmond (1974) employed a modified ordinary least squares (MOLS) method (Førsund et al., 1980).

Given the deterministic statistical frontier model,

$$y_i = f(x_i; \beta_i) \exp(-\varepsilon_i) \qquad (3.9)$$

and the frontier output for the i-th farm

$$\hat{y}_i = f(x_i; \beta_i)$$

The technical efficiency of the i-th farm is predicted by

$$TE_i = y_i / \hat{y}_i = (x_i; \beta_i) \exp(-\varepsilon_i) \ / (x_i; \beta_i) = \exp(-\varepsilon_i) \qquad (3.10)$$

For a deterministic statistical frontier model, technical efficiency of individual farms is predicted by the ratio of frontier output to observed output. However, there were some problems (mentioned in the following section) with the estimation techniques and, hence, suggestions for overcoming these problems were put forward by econometricians, including Gabrielson (1975) and Green (1980).

d) Stochastic frontier

All forms of deterministic frontier model suffer from a common deficiency in explaining production activities, as they ignore the absolute truth that farms' performance can be affected by factors beyond the control of the producer. These factors cover a wide range of issues, including weather, machine performance, supply of raw materials and so on. Furthermore, there are other factors associated with the production process which appears to be under the control of the producers, but in reality, it is very difficult to have full control over them in terms of warding off their effects as well as maintaining a perfect or optimal conditions. The effects of exogenous shocks, measurement of related matters, inclusion of exogenous variables etc. can be taken as examples. Each one of these factors may affect the production activities favourably or unfavourably and ultimately their combined effect may contribute positively or negatively causing a variation in output. This combined effect is generally termed 'statistical noise'. The standard interpretation of statistical noise, as given by Førsund et al., (1980, p. 13),

"....that first, there may be measurement error (hopefully on the dependent variable and not on the independent variables). Second, the equation may not be completely specified (hopefully with the omitted variables individually unimportant)".

However, input-output relationships in production economics should consider the effect of statistical noise. Stochastic frontiers contain this noise and it is the first and foremost differentiating element between stochastic frontiers and deterministic statistical frontiers.

(i) Overcoming the problems with the earlier frontiers

Stochastic frontier models are not subject to any of the major problems associated with the previous models. For example, the major problem associated with the deterministic frontier model is that it makes no allowance for statistical noise and attributes all variation in output (excluding variation caused by inputs) to technical inefficiency. On the other hand, the OLS model attributes all variation in output (not associated with variation in inputs) to statistical noise and does not consider technical inefficiency effects. At this point, what is required is a model that takes into account a combination of statistical noise and technical inefficiency in explaining variation in output (excluding variation caused by inputs). Considering these issues, Aigner et al., (1977), and Meeusen and Van den Broeck (1977) almost simultaneously introduced the stochastic frontier models. Battese and Corra (1977) followed them with some modification in the parameterisation of the variance parameter. These models are devoid of the major deficiency of the deterministic frontier models in terms of random disturbances by incorporating two error terms, one for statistical noise and the other for technical inefficiency. This is why these models are often called 'composed error' models. The remarkable virtue of this composed error (frontier) model is that the total variation in output due to statistical noise and technical inefficiency can be decomposed, at least in principle.

Consider the model given in equation (3.9), while using a different error structure, where

$$\varepsilon_i = \xi_i + \tau_i \qquad i = 1,2,3,\ldots, n \qquad (3.11)$$

So equation (3.9) becomes (taking a log-linear form)

$$\ln y_i = \beta_0 + \sum_{i=1} \beta_i \ln x_i + \xi_i - \tau_i \qquad [-\infty \leq \xi_i \leq \infty; \tau_i \geq 0] \qquad (3.12)$$

where ξ_i represents symmetric random disturbances (also called 'statistical noise') beyond the control of the production unit and is assumed to be independently and identically distributed as $N \sim (0, \sigma_\xi^2)$; whilst τ_i represents asymmetric random errors under the control of the production unit, which is termed the inefficiency effects and is assumed to be distributed independently of ξ_i. This non-negative inefficiency error term τ_i is the cornerstone of the stochastic frontier model and is derived from a normal distribution, $N \sim (0, \sigma_\tau^2)$ truncated at above zero. Thus, this error term is half normally distributed. Again, τ_i can take either an exponential or a half-normal distribution (Aigner et al., 1977); while, Meeusen and Van den Broeck (1977) considered only exponential distribution for this error term. Indeed, specifications of this stochastic model depend on the features of two error terms.

The structure of the stochastic production frontier model (3.12) is such that, if the one-sided positive disturbance, τ_i, is deducted from the stochastic frontier values, each farm's output must lie on or below its frontier. In other words, output values are bounded from above by the stochastic variables ($\beta_i \ln x_i + \xi_i$). The shortfall of observed output compared to frontier output is attributed to the factors which are under the control of the production units; at the same time, the frontier output can vary, since the statistical noise component, ξ_i, can take either a positive or negative, or even a zero value. In the words of Aigner et al., (1977, p. 25):

> "… Any such deviation is the result of factors under the firm's control, such as technical and economic inefficiency, the will and effort of the producer and his employees, and perhaps such factors as defective and damaged product. But the frontier itself can vary randomly across firms, or over time for the same firm. On this interpretation, the frontier is stochastic, with random disturbance $0 \leq \xi_i \geq 0$ being the result of favorable as well as unfavorable external events such as luck, climate, topography, and machine performance. Errors of observation and measurement on [output] y_i constitute another source of $0 \leq \xi_i \geq 0$".

Given the input bundle and technology, when $\tau_i = 0$, the production function is considered to be the best-practice one, yielding maximum output (theoretically, a stochastic frontier output); and when $\tau_i > 0$, the output level is less than the maximum, due to technical inefficiency. The greater the quantity by which the observed output falls short of the stochastic frontier output, the higher is the extent of technical inefficiency. However, the frontier outputs vary around the deterministic part ($\beta_i \ln x_i$), since the random error ξ_i can be positive or negative.

(ii) Schematic diagram explaining the stochastic frontier

The aforementioned important features of the stochastic frontier model are illustrated graphically with diagram 3.2, drawing on the work of Coelli et al., (2005, p. 243-4). Farms that produce single output '*y*', using input vector $\boldsymbol{x}_i$ and the corresponding stochastic production frontier (of Cobb-Douglas functional form), take the specifications of the model (3.12) as

$ln\, y_i \;=\; \beta_0 + \sum_{i=1} \beta_i\, ln\, x_i + \xi_i - \tau_i \qquad [-\infty \leq \xi_i \leq \infty;\ \tau_i \geq 0]$

$$\text{or, } y_i = exp\,(\beta_0 + \sum \beta_i\, ln\, x_i + \xi_i - \tau_i) \tag{3.13}$$

$$\text{or, } y_i = \underbrace{\{exp\,(\beta_0 + \sum \beta_i\, ln\, x_i\}}_{\textit{deterministic part}} \quad \underbrace{\{exp(\xi_i)\}}_{\textit{statistical noise}} \quad \underbrace{\{exp\,(\tau_i)\}}_{\textit{tech. inefficiency}} \tag{3.14}$$

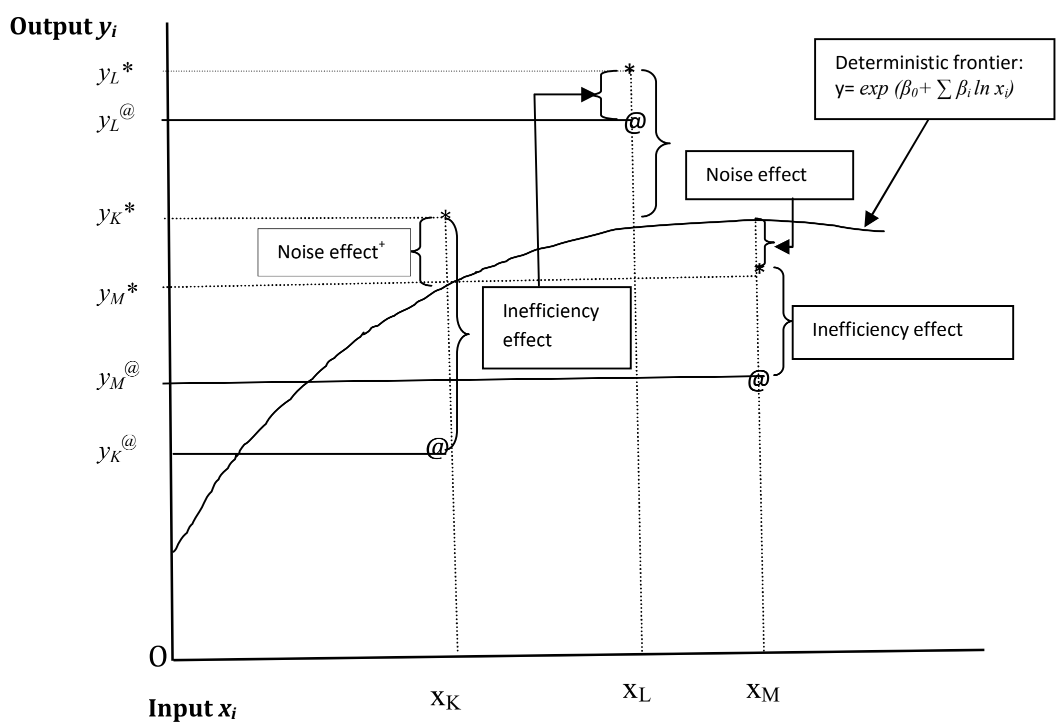

Figure 3.2: Schematic diagram of the stochastic production frontier and output gap

The input vector is presented on the horizontal axis and output on the vertical axis. For the convenience of comparative discussion, only three farms, K, L and M are taken into consideration. The deterministic component of the frontier model is [$exp\ (\beta_0 + \sum \beta_i\ ln\ x_i$], and its shape (figure 3.2) indicates that the production process is subject to the law of diminishing returns to scale. Assume that farm K uses input vector x_K and produces y_K amount of output; likewise, the corresponding input vector and output level for farm L are x_L and y_L respectively and these are x_M and y_M for farm M in order. These actual output levels are labelled using the at-the-rate [@] sign; while the so-called frontier outputs are indicated by the asterisk [*] sign. In the case of no inefficiency effects (i.e., τ_K =0, τ_L =0 and τ_M =0) on the production process of the three farms, the frontier levels of output for farms K, L and M respectively would be:

$$\left.\begin{aligned} y_K^* &\equiv exp\ (\beta_0 + \sum \beta_K \ln x_K + \xi_K) \\ y_L^* &\equiv exp\ (\beta_0 + \sum \beta_L \ln x_L + \xi_L) \\ y_M^* &\equiv exp\ (\beta_0 + \sum \beta_M \ln x_M + \xi_M) \end{aligned}\right\} \qquad (3.15)$$

where, ξ_K, ξ_L and ξ_M denote the statistical noise effects for these farms in order. Along with the frontier and actual outputs, there is the issue of 'output gap' (commonly known as yield-gap), which indicates how far the actual output level is away from the frontier level. Thus, the 'output gap' for a farm is the difference between the frontier level of output and the actual level of output of that farm.

From figure 3.2, it is evident that the frontier output for farm K lies above the deterministic part, while exceeding the output corresponds to the deterministic part because the systematic random error, ξ_K, is associated with a favourable production environment; thus, the noise effect is positive i.e., ξ_K>0. In contrast, for farm M, the situation is opposite; the frontier output for farm M lies below the deterministic part because the systematic random error, ξ_K, is associated with an unfavourable production environment; thus, the noise effect is negative i.e., ξ_M < 0. However, it is interesting for farm K that the observed output lies below the deterministic part, although its frontier output is above the deterministic part; this is because of the combined effects of statistical noise and technical inefficiency; here negative inefficiency effects outweigh the positive noise effect i.e., $\xi_K - \tau_K < 0$.

Usually, the unobserved frontier outputs tend to lie around (above or below) the deterministic part of the frontier, whereas observed outputs tend to fall below the deterministic part of the frontier. However, both frontier output and observed output together can lie over (see farm L) or underneath (see farm M) the deterministic part. Indeed, they could lie above the deterministic part insofar as the noise effect is positive and greater than the inefficiency effect. Hence, the necessary condition is that the noise effect is positive and the sufficient condition is that the positive noise effect outweighs the negative inefficiency effect. This situation is depicted in farm L; here, ξ_L – $\tau_L > 0$. Needless to say, farm M shows the opposite situation, where both frontier and observed outputs lie beneath the deterministic part. Here, the negative noise effect reinforces the negative inefficiency effect and determine the observed output further below the deterministic part.

3.3 The Stochastic Frontier Models and Estimation Methods

3.3.1 The empirical econometric models

The present study employs the following stochastic frontier models for estimation of the parameters involved in predicting productive efficiencies

$$y_i = f\ (\boldsymbol{x}_i;\ \boldsymbol{\beta}) + \xi_i - \tau_i \quad (\xi_i - \tau_i = \varepsilon_i \text{and } i = 1, 2, . \ . \ . \ , n) \tag{3.16}$$

(for estimating technical efficiency)

$$C_i \ = g(\boldsymbol{y_i}, \boldsymbol{p_i}; \boldsymbol{\beta}) + \xi_i + \tau_i \qquad (\xi_i + \tau_i = \varepsilon_i \text{and } i = 1, 2, \ldots., n\ ) \tag{3.17}$$

(for estimating cost efficiency)

Both of the models accommodate the following inefficiency model as proposed by Battese and Coelli (1995)

$$\tau_i = \ z_i\delta + \omega_i = \mu_i + \ \omega_i \tag{3.18}$$

(The notations bear the same meanings as in section 2.3.4 of chapter 2; while C_i and p_i refer to total cost of production and prices/cost of input variables).

The principal objective of stochastic frontier analysis involves prediction of efficiency which follows the estimation of intercept *(β_0)*, slope parameters ($\beta_1, \beta_2 \ldots \beta_n$), variance parameters($\sigma_\tau^2$, σ_ξ^2) and other relevant parameters. Estimates of these technology parameters play an important role in obtaining appropriate estimates of τ_i; because inappropriate and inconsistent estimates of technology parameters result in misleading estimates of technical efficiency (Green, 2008). Thus, before dealing with estimation of τ_i, it is necessary to judge the techniques of estimating technology parameters. In estimating parameters, two commonly used approaches, the Ordinary Least Square (OLS) or its variants, and Maximum Likelihood (ML) methods are often employed. However, there are contrasting features of OLS and ML estimates, as well as their applications. For example, if ξ_i is assumed to be normally distributed, then ML and OLS estimators of the intercept and slope parameters i.e., βs, are identical for both simple and multiple regressions. On the other hand, estimators of the variance of ξ_i using OLS and ML are different for small samples, but they converge in large samples. The ML method is usually termed the large-sample method and it has a wider range of applications. This method has some advantages over the OLS method; for example, the ML method can deal with nonlinear parameters, while OLS is not suitable for non-linear models. Moreover, the theoretical properties of the ML method are stronger than that of OLS (Gujarati and Sangeetha, 2007, p. 116, 120). (Appendices 2 and 3 present the statistical procedures of estimating parameters with OLS and ML methods respectively).

3.3.2 Methods of estimating stochastic frontier models

The estimation of technology parameters is not as straightforward in the stochastic models as it is in traditional econometric models because of the structural differences between the error terms, particularly the non-negative error term (τ_i). The technical inefficiency term makes the estimation process complicated. Logically, the inefficiency component should take the non-zero mean, since $\tau_i \geq 0$; this is the main differentiating factor between the traditional average model and stochastic frontier model. Except for the inefficiency component, the structure of the traditional average model and stochastic frontier model is the same; furthermore, the assumptions regarding the common error term (statistical noise, ξ_i) are identical for both types of models. This symmetric statistical noise term is assumed to be independently and identically distributed and also independent of the one-sided error term (τ_i). Thus, the composed error term $\varepsilon_i = \xi_i - \tau_i$, is asymmetric. It is also assumed that ξ_i and τ_i, are distributed independently of x_i. Under these conditions, OLS provides consistent estimates for the *slope coefficients* (β_1, β_2, β_3,. . ., β_n,) only, but not for the *intercept coefficient* (β_0); it (the intercept coefficient) is biased downwards, since $E(\varepsilon_i) = - E(\tau_i) \leq 0$. In addition, the OLS method does not provide predictions of farm-specific technical efficiency.

Considering the biased estimate of the intercept coefficient, Winsten (1957) (cited in Kumbhakar and Lovell 2000, p. 70) prescribed the Corrected Ordinary Least Square (COLS) method, while Afriat (1972) and Richmond (1974) proposed the Modified Ordinary Least Square (MOLS) method in order to correct the biased intercept estimate. Although both of these techniques are relatively less complicated, they suffer from serious deficiencies, including the fact that they make no allowances for random shocks etc. This means that these techniques are in the context of the deterministic frontier (Kumbhakar and Lovell, 2000, p. 70-72).

However, the main objective of a production frontier analysis is to predict technical efficiency; prior to this, it is necessary to estimate production technology parameters β's in $f(x; \beta)$. The complicated part of this prediction process involves decomposition of the composed error ε_i into separate estimates of statistical noise, ξ_i and technical inefficiency, τ_i, for each farm, and this requires distributional assumptions about the error components. Considering the complexity of the entire estimation, the method of maximum likelihood is appropriate. Coelli et al., (2005, p. 245) report, "the ML estimator is asymptotically more efficient than the COLS estimator". Indeed, in a Monte Carlo study, Coelli (1995a) found that the ML estimator significantly outperformed the COLS estimator when the contribution for the technical inefficiency effects to the total variance was comparatively large.

3.4 Estimating Parameters: The Maximum Likelihood Method

3.4.1 The distributional specifications

It is imperative that a random variable follows a distributional pattern to comply with the method of maximum likelihood estimation. Thus, each of the two random errors terms (ξ_i and τ_i) in the stochastic frontier model must have distributional specifications. It is common to assume that the symmetric error term ξ_i follows a normal distribution with a zero mean and constant variance, whilst the one-sided non-negative technical inefficiency component can assume several distributional patterns, namely, half normal, exponential, truncated normal and gamma. Accordingly, these two error terms together can assume the following distributional specifications, which are often used in empirical studies.

(i) ***The normal-half normal model***

(a) $\xi_i \sim$ iid $N(0, \sigma^2_\xi)$

(b) $\tau_i \sim$ iid $N^+(0, \sigma^2_\tau)$, (non-negative half normal truncated at zero)

(c) ξ_i and τ_i are distributed independently of each other, and of the explanatory variables

(ii) ***The normal-exponential model***

(a) $\xi_i \sim$ iid $N(0, \sigma^2_\xi)$

(b) $\tau_i \sim$ iid $P(\lambda, 0)$, (exponential with mean λ)

(c) ξ_i and τ_i are distributed independently of each other, and of the explanatory variables

(iii) ***The normal-truncated normal model***

(a) $\xi_i \sim$ iid $N(0, \sigma^2_\xi)$

(b) $\tau_i \sim$ iid $N^+(\mu, \sigma^2_\tau)$

(c) ξ_i and τ_i are distributed independently of each other, and of the explanatory variables

(iv) ***The normal-gamma model***

(a) $\xi_i \sim$ iid $N(0, \sigma^2_\xi)$

(b) $\tau_i \sim$ iid $G(\lambda, m)$, (Gamma with mean λ and degrees of freedom m)

(c) ξ_i and τ_i are distributed independently of each other, and of the explanatory variables

Aigner et al., (1977) used both the normal-half normal and the normal-exponential distributions in their estimations, while Meeusen and Van den Broeck (1977) used the normal-exponential distribution only for the composed error term in their analysis. Later, Stevenson (1980) proposed the truncated normal model, identifying the limitations of the half-normal model and Green (1990) came up with the gamma model. However, the appropriateness of the distributional forms of the one-sided error term is still a debated issue. In fact, assumptions regarding the distribution of the inefficiency errors depend mostly on the preferences of the researchers. Coelli et al., (2005) state that it is often the issue of computational convenience that leads the choice of distributional specification. The authors also argue that theoretical issues may lead to consideration of the distributional specifications as saying,

". . . some researchers avoid half-normal and exponential distributions because they have a mode at zero, implying that most inefficiency effects are in the neighbourhood of zero and the associated measure of technical efficiency would be in the neighbourhood of one" (Coelli et al., 2005, p. 252).

In contrast, the other two distributions of τ_i—the truncated normal and the gamma—are flexible, allowing for a wider range of distributional shapes. Based on the abovementioned information, efficiency models can be classified into two groups in terms of flexibility in the distributional pattern of τ_i : the half-normal and exponential models, which are non-flexible, and the truncated and gamma models, which are flexible. This flexibility, however, comes with additional parameters to be estimated, which entail computational complexity.

Empirical evidence has already established the fact that mean efficiency is sensitive to the choice of distributional assumption, but it is yet to be confirmed whether individual efficiencies are sensitive to distributional assumptions (Kumbhakar and Lovell, 2000, p. 90). However, Coelli et al., (2005, p. 252) argue that the rankings of the farms, based on predicted efficiency, are often quite robust to distributional choice. Considering the theoretical issues and reality of the present study, estimation techniques of normal-half normal and normal truncated normal distributional models have been considered and are discussed below.

3.4.2 The normal-half normal model for inefficiency effect

Consider the stochastic frontier model in equation (3.12) and the assumptions given under the normal-half normal model in section 3.4.1. In the normal-half normal model, assumption (a) is the same as that in the traditional econometric model and is maintained throughout; assumption (b) is based on the argumentative proposition that τ has a mode of $\tau = 0$, meaning that the modal value of technical inefficiency is zero; assumption (c) is such that it complies with the preconditions of the method of maximum likelihood.

The estimation technique primarily involves probability density functions and joint density functions of the error components. The density functions of two error components $-\infty \leq \xi_i \geq +\infty$ and $\tau_i \geq 0$ are respectively

$$f(\xi) = \frac{1}{\sigma_\xi\sqrt{2\pi}} . exp\,(-\frac{\xi^2}{2{\sigma_\xi}^2}) \tag{3.19}$$

$$f(\tau) = \frac{2}{\sigma_\tau\sqrt{2\pi}} . exp\,(-\frac{\tau^2}{2{\sigma_\tau}^2}) \tag{3.20}$$

Since both of the error terms are independent of each other, the product of their individual densities yields their joint density

$$f(\xi,\tau) = \frac{2}{2\pi\sigma_\xi\sigma_\tau} . exp\left(-\frac{1}{2{\sigma_\tau}^2}\tau^2 - \frac{1}{2{\sigma_\xi}^2}\xi^2\right) \tag{3.21}$$

The composed error term, ε is made up of ξ and τ, i.e., $\varepsilon = \xi - \tau$. Now, the joint density of the inefficiency component, τ and the composed error term ε, is

$$f(\tau, \varepsilon) = \frac{2}{2\pi\sigma_\xi\sigma_\tau} . exp\,(-\frac{1}{2{\sigma_\tau}^2}\tau^2 - \frac{(\varepsilon+\tau)^2}{2{\sigma_\xi}^2}) \tag{3.22}$$

Integrating τ out of f (τ, ε), the following marginal density of ε, is obtained,

$$f(\varepsilon) = \int_0^\infty f(\tau, \varepsilon)d\tau$$

$$= \frac{2}{\sqrt{2\pi\sigma}}.\left[1 - \Phi\left(\frac{\varepsilon\lambda}{\sigma}\right)\right].exp\left(-\frac{\varepsilon^2}{\sigma}\right)$$

$$= \frac{2}{\sigma}.\varphi\left(\frac{\varepsilon}{\sigma}\right).\Phi\left(-\frac{\varepsilon\lambda}{\sigma}\right) \qquad -\infty \leq \varepsilon \leq +\infty \qquad (3.23)$$

where $\sigma^2 = \sigma_\xi^2 + \sigma_\tau^2$ and $\lambda = \sigma_\tau / \sigma_\xi$. Φ (.) refers to the standard normal cumulative density function, evaluated at $\varepsilon\lambda/\sigma$ (Aigner et al., 1977) and φ (.) indicates the standard density function. This marginal density function is asymmetric around zero with the following mean and variance

$$E(\varepsilon) = -E(\tau) = -\frac{\sqrt{2}}{\sqrt{\pi}}\sigma_\tau \qquad (3.24)$$

$$V(\varepsilon) = V(\tau) + V(\xi) = \sigma_\tau^2\frac{\pi-2}{\pi} + \sigma_\xi^2 \qquad (3.25)$$

From the above equations (3.24) and (3.25), it is evident that normal-half normal distribution involves only two variance parameters, σ_ξ and σ_τ.

(Figure 3.4 depicts three different normal-half normal distributions based on the combinations of σ_ξ and σ_τ.)

Exploiting equation (3.23), the log likelihood function (as equation A 3.8 of Appendix 3) of the observed 'n' farms is

$$ln\,L(\boldsymbol{y}|\,\beta, \sigma, \lambda) = \frac{n}{2}ln\left(\frac{\pi\sigma^2}{2}\right) + \sum_{i=1}^{n} ln\,\Phi\left(-\frac{\lambda\varepsilon_i}{\sigma}\right) - \frac{1}{2\sigma^2}\sum_{i=1}^{n}\varepsilon_i^2 \qquad (3.26)$$

where **y** is a vector of log of outputs; ε_i is the composite error term; $\varepsilon_i \equiv \xi_i - \tau_i = ln\,y_i - \boldsymbol{x}_i'\beta$; and Φ (.) refers to the cumulative distribution function of the standard normal variable evaluated at *x*. This log likelihood function (3.26) is maximised with respect to the parameters in order to obtain the maximum likelihood estimates of relevant parameters that are asymptotically consistent. Usually, the maximisation of a log-likelihood function is carried out by taking the first derivatives with respect to the parameters, and then each of these derivatives is set to zero. However, this technique is applicable if the first derivatives are linear, i.e., not complex, such as the first derivatives from the equation (3.26). Actually, the first derivatives, in this case are highly non-linear and it is not possible to estimate the parameters β, σ, and λ analytically, i.e., to solve the first derivatives. Instead, this problem is solved through the *iterative optimisation procedure,* where the starting values for the unknown parameters are sensibly chosen at the outset and then systematically upgraded until the values that maximise the log likelihood function are found. When the optimum values have been obtained, necessary information is available to predict the mean technical efficiency of the sample observations. In fact, Aigner et al., (1977) suggested $\{1- E(\tau)\}$ as an estimator of the mean technical efficiency for the sample observations and it is evident from equation (3.24) that only the estimate of σ_τ is enough to predict the mean efficiency. However, it is also desirable to predict technical efficiency for individual farms/producers. Indeed, this is the fundamental idea that motivated J. M Farrell (1957) to originate the concept of production frontiers and thereby compare levels of productive efficiency of the firms across industries. This means that the work of Aigner et al., (1977) partially fulfilled the desire of Farrell. As Førsund et al., (1980, p. 14) report,

> "…… This constitutes the main weakness of the stochastic frontier model: it is not possible to decompose individual residuals into their two components, and so it is not possible to estimate technical inefficiency by observation. The best that one can do is to obtain an estimate of mean inefficiency over the sample".

However, it is the work of Jondrow et al., (1982) that paved the way for predicting the technical efficiency of individual farms. The authors separated the combined information by exploiting the conditional distribution of τ_i given ε_i, and expressed the view that either the mean or the mode of this distribution can be considered as a point estimate of τ_i. Hence, the authors' logic is clear and substantive, since $\varepsilon_i = \xi_i - \tau_i$; therefore, the basic solution path relates to extracting information on τ_i from ε_i. According to Jondrow et al., (1982), for half normal distribution of τ_i, $[\tau_i \sim (N^+ (0, \sigma_\tau^2)]$, the conditional density of τ_i given ε, is the ratio of the density of ε to the joint density of τ_i and ε_i, and is given by

$$f(\tau/\varepsilon) = \frac{f(\tau,\varepsilon)}{f(\varepsilon)}$$

$$= \frac{2}{\sigma_* \sqrt{2\pi}} . exp\left[-\frac{(\tau-\mu_o)^2}{2\sigma_*^2}\right] / \left[\left(1 - \Phi(-\frac{\mu_o}{\sigma_*})\right)\right] \quad (3.27)$$

In accordance with the specifications of Jondrow et al., (1982), here $\mu_o = - \sigma^2_\tau \varepsilon/\sigma^2$ and $\sigma^2_* = \sigma^2_\tau \sigma^2_\xi /\sigma^2$. As mentioned earlier, either the mean or the mode of this conditional distribution $N^+ (\mu_o, \sigma^2_*)$, is used as a point estimator of τ_i. The mean is given by

$$E(\tau_i|\varepsilon_i) = \mu_{oi} + \sigma_* \left[\frac{\varphi(-\mu_{oi}/\sigma_*)}{1 - \Phi(-\mu_{oi}/\sigma_*)}\right]$$

Since $-\mu_{oi}/\sigma_* = \varepsilon_i \lambda/\sigma$, and $\lambda = \sigma_\tau / \sigma_\xi$,

$$E(\tau_i|\varepsilon_i) = \sigma_* \left[\frac{\varphi(\varepsilon_i\lambda/\sigma)}{1-\Phi(\varepsilon_i\lambda/\sigma)} - \left(\frac{\varepsilon_i\lambda}{\sigma}\right)\right] \quad (3.28)$$

The second or alternative point estimator for τ_i is the mode of the conditional distribution (3.27) and is given by

$$M(\tau_i|\varepsilon_i) = -\varepsilon_i \left(\frac{\sigma_\tau^2}{\sigma^2}\right) \qquad if\ \varepsilon_i \le 0 \quad (3.29)$$

$$= 0 \qquad if\ \varepsilon_i > 0$$

In the above equations (3.28) and (3.29), μ_* and σ_* are unknown and are to be estimated in order to obtain estimate $E(\tau_i/\varepsilon_i)$, (say,$\hat{\tau}_i$). After ascertaining the point estimates of τ_i, the prediction of technical efficiency of each farm is straightforward. Thus, the technical efficiency of the i-th farm is

$$TE_i = exp\,(-\hat{\tau}_i) \quad (3.30)$$

Hence, estimates of either [E $(\tau_i|\varepsilon_i)$] or [M $(\tau_i|\varepsilon_i)$] can be used, but a mean based estimator is used more frequently. This method is referred to as the JLMS-method.

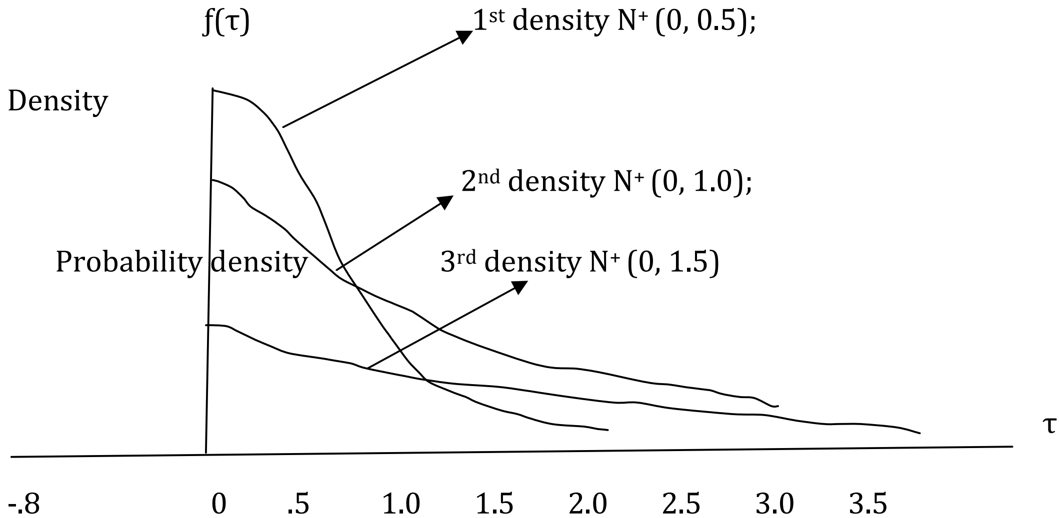

Figure 3.3: Half-normal distribution of the non-negative error term

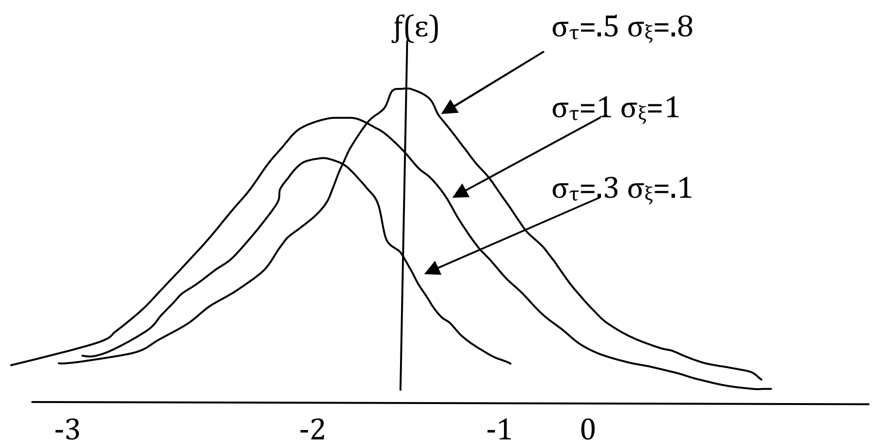

Figure 3.4: Normal-half normal distribution of composed error term

On the other hand, Battese and Coelli (1988) suggested an alternative predictor for technical efficiency of individual farms using the estimate of [E $(\tau_i|\varepsilon_i)$] as

$$TE_i = E\,\{\exp(-\hat{\tau_i})\,|\varepsilon_i\} \tag{3.31}$$

$$= \left[\frac{1-\Phi\left(-\frac{\mu_O}{\sigma_*}+\sigma_*\right)}{1-\Phi\left(-\frac{\mu_O}{\sigma_*}\right)}\right].exp\left(-\mu_{oi}+\frac{\sigma_*^2}{2}\right) \tag{3.32}$$

Although both 'JLMS' and Battese and Coelli (1988) methods use the same mean based point estimate of [E $(\tau_i|\varepsilon_i)$], they employ different formulae (i.e., equations 3.30 and 3.31 respectively) to predict technical efficiency. Therefore, the results will be different, because $\exp(-\hat{\tau_i}) \neq E\,\{\exp(-\hat{\tau}_i)\,|\varepsilon_i\}$. Kumbhakar and Lovell (2000, p. 78) favour the Battese and Coelli (1988) estimator because $E\,\{\exp(-\hat{\tau}_i)\,|\varepsilon_i\}$ is more consistent with the definition of technical efficiency.

The relationship between error terms (i.e., $\varepsilon = \xi_i - \tau_i$) shows that the distribution of the composed error term depends on the one-sided error term τ_i, since the other error term, ξ_i follows a symmetric distribution. If there exists no technical inefficiency i.e., $\tau_i = 0$, then $\varepsilon = \xi_i$, meaning the composed error term collapses to symmetric distribution and the data do not contain information on technical inefficiency. Again, if there exists technical inefficiency, i.e., $\tau_i > 0$, then $\varepsilon = \xi_i - \tau_i$, which implies that the distribution of the composed error is negatively skewed. Alternatively, it is said that if the composed error term is negatively skewed, then technical inefficiency is present. However, the normal-half normal distribution has only two basic variance parameters, σ_ξ and σ_τ, and two derived parameters, σ and λ, for convenience. Based on the two basic parameters, three negatively skewed distributions of ε are depicted in figure 3.4. Hence, $\sigma_\tau > 0$, for all the cases, and the distributions have negative modes (and means).

3.4.3 The normal-truncated normal model for inefficiency effect

Aigner et al., (1977) assumed that the one-sided error term for inefficiency component τ is distributed with a half normal density, having a mode of $\tau = 0$. Stevenson (1980) raised questions about the justification for this assumption, saying, "it is not clear, however, why the mode of τ should be expected to occur at $\tau = 0$" (Stevenson (1980) used notation u instead of τ). The author also argued that, since production activities are conducted by human beings or human institutions, the likelihood of a non-zero mode for the inefficiency component τ is more tenable. However, the author developed a general model which subsumes both the cases of zero and non-zero modes for the distribution of technical inefficiency component τ. This model is known as the truncated-normal inefficiency model.

The estimation technique with the normal-truncated normal model follows the same path as that for the normal-half normal model. However, the estimation process is more complicated because of the involvement of additional parameters.

The density function of the symmetric error term ξ is the same as in the case of the normal- half normal model (equation 3.19), which is reproduced here

$$f(\xi\ ) = \frac{1}{\sigma_{\xi}\sqrt{2\pi}}.\, exp\ (-\frac{\xi^2}{2{\sigma_{\xi}}^2}) \tag{3.33}$$

While the truncated normal density function for the error term τ > 0 is

$$f(\tau\ ) = \frac{1}{\Phi(-\mu/\sigma_{\tau})\ \sigma_{\tau}\ \sqrt{2\pi}}.\, exp\ (-\frac{(\tau-\mu)^2}{2{\sigma_{\tau}}^2}) \tag{3.34}$$

here, Φ(.) stands for the standard normal cumulative distribution function; μ refers to the mode of the error term τ, truncated below at 0. Again, ƒ (τ) can also be termed as the density of a random variable, which is normally distributed and likely to have a mean μ (μ≠0), which is truncated below at 0 (Kumbhakar and Lovell, 2000, p. 83).

Likewise, the joint density function of ξ and τ can be obtained by multiplication of their individual density functions as

$$f(\xi,\tau) = \frac{2}{(2\pi\sigma_{\xi}\sigma_{\tau})\ \Phi(\ \mu/\sigma_{\tau}}.\, exp\left(-\frac{(\tau-\mu)^2}{2{\sigma_{\tau}}^2} - \frac{1}{2{\sigma_{\xi}}^2}\xi^2\right) \tag{3.35}$$

The composed error term, ε is made up of ξ and τ, i.e., ε = ξ – τ. Now, the joint density of inefficiency component, τ and the composed error term ε, is

$$f(\tau\,,\varepsilon) = \frac{1}{(2\pi\sigma_{\xi}\sigma_{\tau})\,\Phi(\mu/\sigma_{\tau})}.\,exp\,(-\frac{(\tau-\mu)^2}{2\sigma_v{}^2} - \frac{(\varepsilon+\tau)^2}{2\sigma_\tau{}^2}) \tag{3.36}$$

Integrating τ out of $f(\tau, \varepsilon)$, the marginal density of ε is

$$f(\varepsilon) = \int_0^{\infty} f(\tau,\varepsilon)d\tau \tag{3.37}$$

$$= \frac{1}{\sigma\sqrt{2\pi}\Phi(-\mu/\sigma_\tau)}\,.\left[\Phi\left(\frac{\mu}{\sigma\lambda} - \frac{\varepsilon\lambda}{\sigma}\right)\right].\,exp\left[-\frac{(\varepsilon+\mu)^2}{2\sigma^2}\right]$$

$$= \sigma^{-1}.\,\varphi\left(\frac{\varepsilon+\mu}{\sigma}\right).\,\Phi\left(\frac{\mu}{\sigma\lambda} - \frac{\varepsilon\lambda}{\sigma}\right).\left[\Phi\left(-\frac{\mu}{\sigma_\tau}\right)\right]^{-1} \quad -\infty \le \varepsilon \le +\infty \tag{3.38}$$

where $\sigma = (\sigma_\xi{}^2 + \sigma_\tau{}^2)^{1/2}$ and $\lambda = \sigma_\tau/\sigma_\xi$. Φ (.) refers to the standard normal cumulative density function, and φ (.) indicates standard normal density function. This marginal density function is asymmetric with the mean

$$E(\varepsilon) = -E(\tau) = \frac{1}{2}\mu a - \frac{\sigma_\tau a}{\sqrt{2\pi}}.\exp\left[-\frac{1}{2}\left(\frac{\mu}{\sigma_\tau}\right)^2\right] \tag{3.39}$$

and variance

$$V(\varepsilon) = V(\tau) + V(\xi) = \mu^2\frac{a}{2}\left(1-\frac{a}{2}\right) + \frac{a}{2}\left(\frac{\pi-a}{\pi}\right)\sigma_\tau^2 + \sigma_\xi^2 \tag{3.40}$$

where, $a = \frac{1}{\Phi(-\mu/\sigma_\tau)}$

At μ = 0, the mean and variance of ε are same as those in equations (3.24) and (3.25); meaning that, at μ = 0, the equation (3.38) collapses into the normal-half normal marginal density function in equation (3.23).

From the above equations (3.39) and (3.40), it is evident that normal-truncated normal distributions have three parameters, μ, σ_ξ and σ_τ.

As per usual practice, by exploiting equation (3.38), the log likelihood function of the observed 'n' farms is

$$ln\, L(\boldsymbol{y}|\, \beta, \sigma, \lambda, \mu) = -\frac{n}{2} ln\, 2\pi - \frac{n}{2} \ln \sigma^2 - n \ln \Phi\left(-\frac{\mu}{\sigma}(\lambda^{-2}+1)^{1/2}\right) + \sum_{i=1}^{n} ln\, \Phi\, \left(\frac{\mu}{\lambda\sigma} -\right.$$

λεiσ− 12σ2i=1nεi+μσ2

$$or,\ \ ln\, L(\boldsymbol{y}|\, \beta, \sigma, \lambda, \mu) = -\frac{n}{2} ln\, 2\pi\sigma^2 - n \ln \Phi\left(-\frac{\mu}{\sigma_\tau}\right) + \sum_{i=1}^{n} ln\, \Phi\, \left(\frac{\mu}{\lambda\sigma} - \frac{\lambda\varepsilon_i}{\sigma}\right) - \frac{1}{2\sigma^2}\sum_{i=1}^{n}\left(\frac{\varepsilon_i+\mu}{\sigma}\right)^2 \quad (3.41)$$

where $\sigma_\tau = \sigma\, (\lambda^{-2} + 1)^{-1/2}$.

where **y** is a vector of log-outputs; ε_i is the composite error term that $\varepsilon_i \equiv \xi_i + \tau_i = ln\, y_i - \boldsymbol{x_i}'\beta$; and Φ (.) refers to the cumulative distribution function of the standard normal variable evaluated at *x*. Maximising the log likelihood function (3.41) with respect to the parameters, the maximum likelihood estimates can be attained and these are asymptotically consistent.

In this way, farm-specific technical efficiency is predicted. The conditional density of τ given ε is the ratio of the density of ε to the joint density of τ and ε, and is given by

$$f(\tau/\varepsilon) = \frac{f(\tau,\varepsilon)}{f(\varepsilon)} \quad (3.42)$$

$$= \frac{1}{\sigma_*\sqrt{2\pi}}.\, exp\left[-\frac{(\tau-\mu_*)^2}{2\sigma_*^2}\right] / \left[\left(1 - \Phi(-\frac{\mu_*}{\sigma_*}\right)\right] \quad (3.43)$$

According to the specifications, $\mu_* = (-\sigma^2_\tau\ \varepsilon + \mu\sigma^2_\xi)/\sigma^2$ and $\sigma^2_* = \sigma^2_\tau\ \sigma^2_\xi\ /\sigma^2$. As mentioned earlier, either the mean or the mode of this conditional distribution N^+ (μ_*, σ^2_*), is used as a point estimator of τ_i. The mean is given by

$$E(\tau_i|\varepsilon_i) = \mu_{*i} + \sigma_*\left[\frac{\varphi(-\mu_{*i}/\sigma_*)}{1-\Phi(-\mu_{*i}/\sigma_*)}\right] \quad (3.44)$$

The second or alternative point estimator for τ_i is the mode of the conditional distribution (3.43) given by

$$M(\tau_i|\varepsilon_i) = \mu_{*i} \qquad if\ \mu_{*i} \geq 0 \quad (3.45)$$

$$= 0 \qquad \text{otherwise}$$

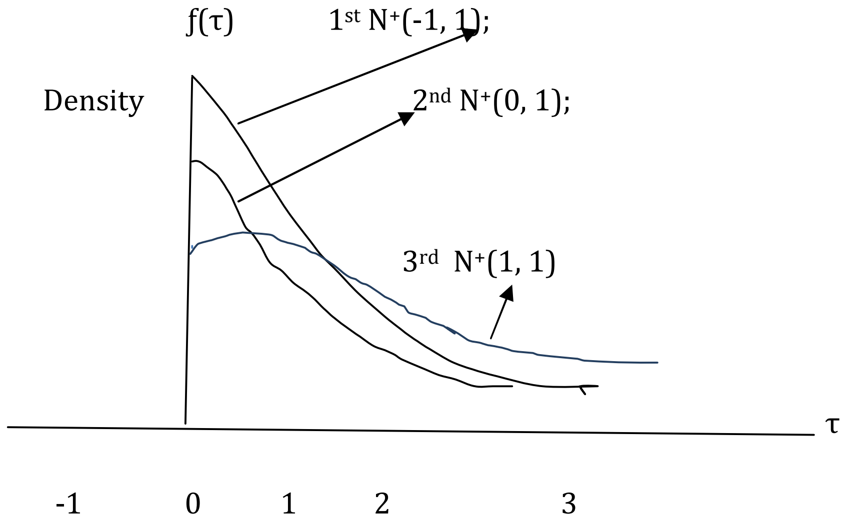

Figure 3.5: Truncated normal distribution of the non-negative error term

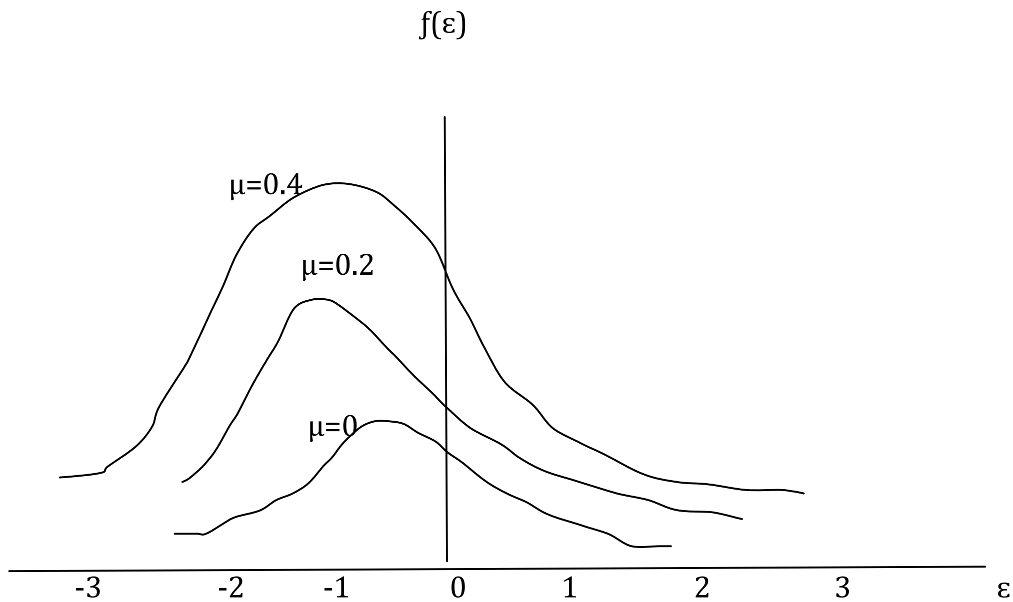

Figure 3.6: Normal-truncated normal distribution of composed error term

In the above equations (3.44) and (3.45), μ_* and σ_* are unknown and are to be estimated in order to obtain estimate $E\ (\tau_i/\varepsilon_i)$, say, $\hat{\tau}_i$. After obtaining the point estimates of τ_i, the technical efficiency of each farm/producer can be predicted easily. According to Battese and Coelli's (1988) formulation, the technical efficiency of the i-th farm is

$$TE_i = E\ \{\exp(-\ \hat{\tau}_i)\ |\varepsilon_i\} \tag{3.46}$$

$$= \left[\frac{1-\Phi\left(-\frac{\mu_*}{\sigma_*}+\sigma_*\right)}{1-\Phi\left(-\frac{\mu_*}{\sigma_*}\right)}\right].\exp\left(-\mu_{*i}+\frac{\sigma_*^2}{2}\right) \tag{3.47}$$

Although the two equations (3.32) and (3.47) look alike, they would not provide the same prediction on technical inefficiency for a given data set because they are based on normal distributions with a zero mean and non-zero mean respectively. Accordingly, equation (3.47) collapses into equation (3.32) when mean $\mu = 0$.

Truncated normal distribution has two parameters—the placement parameter μ and spread parameter σ_τ. Figure 3.5 presents the shape of three truncated normal distributions with different values of the parameters.

As mentioned earlier (in section 3.4.2), negatively skewed distribution indicates the existence of technical inefficiency. The normal–truncated normal distribution contains parameters, μ, σ_ξ and σ_τ. Figure 3.6 presents three normal–truncated distributions with negative modes (and means).

3.4.4 Inefficiency models and alternative estimation procedures

The method of estimating the generalised stochastic frontier (which subsumes the inefficiency effect model) is still a debated issue due to the fact that some authors use a two-stage procedure, while others go for a single-stage. For example, the early empirical works that initiated the incorporation of the inefficiency model into the stochastic frontier analysis, including Kalirajan (1981, 1982, 1984 and 1985), Kalirajan and Flinn (1983), and Pitt and Lee (1981), followed a two-stage method of estimation. However, many econometricians and researchers criticised this method on theoretical and logical grounds. Kumbhakar et al. (1991) argue that the two-stage estimation process provides inconsistent parameter estimates, resulting in inappropriate estimates of technical inefficiency. In line with Kumbhakar (1991), Battese and Coelli (1993, p. 2) criticise the two-stage methods as saying,

"... the methods of estimation of the parameters of the second-stage inefficiency model are based on assumptions which are clearly false, because the effects of the estimation of the stochastic frontier model were not accounted for".

The authors further point out that the inefficiency effects, (τ_i), are assumed to be independently distributed, which is maintained in the first-phase of the two-stage estimation process; however, in the second-phase, the predicted inefficiency effect, ($\hat{\tau}$), is regressed on variables associated with inefficiency effects (violating the assumption upheld in the first phase). In other words, the assumption that τ_is are independent by definition clearly contradicts the specification in the second phase. In defending the two-stage procedure, Kalirajan (1991) mentioned that socioeconomic variables should be incorporated into the production frontier model indirectly because they have an indirect effect on production. Nevertheless, several authors including Kumbhakar et al., (1991), Reifschneider and Stevenson (1991) and Huang and Liu (1994) proposed an alternative way of estimation, which is termed a 'single-stage' procedure. With the single-stage procedure, the parameters of the stochastic frontier and the inefficiency model are estimated simultaneously, assuming appropriate distributional specifications associated with inefficiency effects. According to the proponents of this method, it provides better estimates, since it is statistically consistent, upholding the underlying assumptions involved. This approach is widely accepted and had been applied in many empirical studies (see Battese and Coelli, 1995; Ajibefun et al., 1996; Battese and Broca, 1997; Coelli and Battese, 1996; Conradie et al., 2006; Karagiannis and Sarris, 2005; Karagiannis et al., 2002; Seyoum et al., 1998; Solis et al., 2009, and Sharma and Leung, 1999 and 2000a). It is worth mentioning that the single-stage approach proposed by Kumbhakar et al., (1991), Reifschneider and Stevenson (1991) and Huang and Liu (1994), could accommodate only cross-sectional data, and Battese and Coelli (1995) further extended this approach to accommodating panel data.

In the two-stage procedure, the specification and estimation of the stochastic production frontier and the prediction of the technical inefficiency effects, (τ_i), are done in the first phase, ignoring the fact that τ_i is a function of some other variables which is contrary to single-stage procedure. Then in the second phase, the *predicted* technical inefficiency effects are regressed on the explanatory variables, which are supposed to explain the technical inefficiency of the farms. Usually, ordinary least squares regression is used in estimating the parameters of the inefficiency model during the second stage of the two-stage procedure; whereas, in the single-stage procedure, both types of estimation are performed simultaneously with maximum likelihood methods. Truly, the single-stage procedure is dominant in the literature of efficiency analysis because of its consistent properties.

The present study, however, accepts the single-stage procedure of estimation following Battese and Coelli (1995). The single-equation model is obtained by incorporating the inefficiency model in the main stochastic frontier model (also called an error component model). For example, incorporation of equation (3.18) in equation (3.16) forms a single equation model. Estimation of parameters of both of the error component and inefficiency models are carried out simultaneously, given distributional assumptions of the error terms. The two variance parameters of the error component model are crucial and parameterised as

$$\sigma_\varepsilon^2 = \sigma_\xi^2 + \sigma_\tau^2 \text{and} \quad \gamma = \sigma_\tau^2/\sigma_\xi^2 + \sigma_\tau^2 \qquad (3.48)$$

The parameter γ is bounded between zero and one. As the parameter $\gamma \rightarrow 0$, $\sigma_\tau^2 \rightarrow 0$, and /or $\sigma_\xi^2 \rightarrow +\infty$, the symmetric error component dominates the one-sided error in determining ε. In a reverse way, as the parameter $\gamma \rightarrow 1$, $\sigma_\xi^2 \rightarrow 0$, and /or $\sigma_\tau^2 \rightarrow +\infty$, the one-sided error component dominates the symmetric error in the determination of ε. If $\gamma = 0$, then the variance of inefficiency effects is zero, and the model collapses into a traditional average response model. Moreover, if $\gamma = 1$, it implies that the deviation from the frontier is only due to inefficiency effects.

3.4.5 Prediction of technical inefficiency

In most cases, analysis of the stochastic frontier model is designed to predict the inefficiency effects. Hence, output-oriented measurements are popular because input-oriented measurements involve relatively a higher number of variables in the estimation process. Moreover, output figures are more easily observable than input variables. Furthermore, it is more convenient to estimate the potential level of output compared to that of inputs. The study, however, fits with the output-oriented approach. The basis of the most commonly used output-oriented measure of technical efficiency (TE) is the ratio of observed output (y_i) to the corresponding frontier output, y_i^*. Thus, the technical efficiency of the i-th farm is

$$TE_i = \frac{y_i}{y_i^*} = \frac{Observed\ output}{Stochastic\ frontier\ output} = \frac{y_i}{exp\ (x_i' \beta + \xi_i)}$$

$$= \frac{exp\ (x_i' \beta + \xi_i - \tau_i)}{exp\ (x_i' \beta + \xi_i)} = exp\ (-\tau_i) \quad (3.49a)$$

However, the Battese and Coelli's (1988) formulation, technical efficiency is the expected value of [exp $(-\tau_i)$] as in equation (3.46) and this measure is widely used in empirical studies. Thus

$$TE_i = E\ \{\exp(-\hat{\tau}_i)\ |\varepsilon_i\} \quad (3.49b)$$

This ratio measures the output of the i-th farm compared to the fully-efficient farm that produces the maximum feasible output using the same input vector in an environment characterised by $\{exp\ (\xi_i)\}$. Indeed, τ_i reflects the difference between y_i and y^*. Accordingly, y_i is equal to y_i^*, when $\tau_i = 0$, meaning $TE_i = 1$. This implies that production is taking place on the stochastic frontier and the farm is producing the maximum possible output, given the inputs bundle; the farm is 100% efficient. If $\tau_i > 0$, the production function will lie below the frontier and the farm is technically inefficient. By definition, the value of the measure of technical efficiency must lie between zero and one. Since the value of TE_i may vary across the farms and even for the same farm over time (see Aigner et al., 1977); it is a random variable, not a parameter. This is why Coelli et al., (2005, p. 245) prefer to use the term 'predict' instead of 'estimate'.

3.5 Cost Efficiency and Methodological Issues

3.5.1 Defining cost efficiency

Cost (or economic) efficiency indicates the ability of a farm to produce a certain amount of output at minimum cost, given the prices of factors associated with the production process. By definition, the measure of cost efficiency (CE) is expressed as the ratio of minimum cost to observed cost. Thus, the cost efficiency of the i-th farm (CE_i) is given by (Coelli et al. 2005, p. 267; Kumbhakar and Lovell, 2000, p. 137)

$$CE_i = \frac{Minimum\ Cost}{Observed\ Cost} \qquad (3.50)$$

This definition applies to the present study. However, in production economics, the basic technique of measuring cost efficiency follows the same principle as measuring technical efficiency; nonetheless, the standards against which cost efficiency is measured are provided by the cost frontier. Kumbhakar and Lovell (2000, p.132) describe these differences in detail. Some of the contrasting features involving the estimation approach, data requirement, information available from efficiency measures, behavioural assumptions and so on are presented below.

First, the production frontier requires information on the inputs used and the resultant outputs, and no price information is needed here; in contrast, the cost frontier generally exploits information on the prices of the inputs used, as well as the total cost of inputs used and output quantities.

Second, the cost frontier requires the behavioural assumption that producers minimise cost; however, no such behavioural assumption is necessary for the production frontier, albeit the rationality assumption of the producer is always there.

Third, technical efficiency is not decomposable, whereas cost/economic efficiency can be decomposed into input-oriented technical efficiency[3] and input allocative efficiency.

3.5.2 Behavioural assumptions and farming practice in study area

This study estimates the productive efficiency of paddy and fisheries grow with the FCDM systems as a means to an end. However, there exist noticeable differences between these two crops in terms of production processes, behavioural assumptions and the motivation of the farmers as far as the study area is concerned. In the case of the first crop, paddy, the technical efficiency was estimated from the production frontier, since the production system fully complies with Zellner et al., (1966) assumption that output is stochastic and endogenous. Also, it is believed that farm operators maximise the mathematical expectation of profit.

On the other hand, the farming practices, as well as behavioural assumptions and motivations, for fisheries production of the study area significantly differ from those for paddy cultivation. Fisheries production (in the gher farming system) in the study area is not consistent with Zellner et al., (1966) argument; rather, it is inclined to the framework of cost minimization. In reality, farm operators put more emphasis on cost minimisation by adopting different types of strategies. Some of the strategies often adopted for cost minimization include insufficient and imbalanced feed supply, harvesting before maturity and so on. Considering this behavioural propositions, fisheries production in the gher farming in the study area justifies cost efficiency.

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[3]Measures of input-oriented technical efficiency and output-oriented technical efficiency are to be taken cautiously because they represent different levels of efficiency scores under non-constant returns to scale in the relevant region of production technology. Input-oriented technical efficiency is necessary, but not sufficient for economic efficiency. In fact, cost or economic efficiency is the product of input-oriented technical efficiency and input allocative efficiency; thus, the magnitude of economic efficiency is less than that of input-oriented technical efficiency; hence, the extent of difference is due to input allocative efficiency (Kumbhakar and Lovell, 2000, p. 133)

According to Kumbhakar and Lovell (2000, p. 132),

> ". . . cost minimization objective is an appropriate objective in many environments. It is particularly appropriate in competitive environments in which input prices (rather than input quantities) are exogenous, and in which output is demand driven, and so also can be considered to be exogenous".

The authors' view applies to the environment which prevails in fisheries production in the study area. Moreover, output (i.e., fisheries) is not storable under gher farming system, thus, it substantiate the use of cost efficiency for fisheries production. As a matter of fact, under gher farming system, most part of a gher is required to be dried out every year in order to allow for paddy cultivation; that means, fisheries are not storable output for the gher farmers. This is such a situation that does not comply with Zellner et al., (1966) assumption of profit maximization. As mentioned by Kumbhakar and Lovell (2000, p. 132), ". . . . output is not storable, and so the output maximization objective that underlies the estimation of output-oriented technical efficiency would be inappropriate". Considering these circumstances, the present study estimates cost efficiency for fisheries production.

3.5.3 Pre-conditions for estimating cost efficiency

When it is reasonable to assume firms minimise costs, and price data are available, the cost efficiency of firms can be predicted using the cost frontier (Coelli et al., 2005, p. 266). As mentioned earlier (section 2.6.1 of chapter 2) that there are two approaches to predicting cost efficiency: the single-equation stochastic cost frontier and the cost system approach (CSA) applying duality. The cost system approach (CSA) is a kind of modification of the single equation approach (Bauer, 1990). Kumbhakar and Wang, (2007) and Bauer, (1990) claim that CSA provides relatively better estimates. However, there are limitations of this approach. A considerable limitation is that it works well only with data set having no zero observations. It is apparent from the estimation techniques (see Wadud, 1999, p. 115-118) that erroneous estimates are likely if zero observations are present in the data set.

Since the data of the present study contain a considerable number of zero observations, it is preferable to use a single equation approach over a cost system approach to estimating cost efficiency. In fact, none of these approaches is perfect; so, choice of any approach depends on the quality of the results obtainable from data. Gong and Sickles (1989) observed that the performance of a single equation model is better than a multi-equation model in estimating cost efficiency. The authors came to this conclusion after a Monte Carlo study of alternative estimators of efficiency (cited in Ahmad and Bravo-Ureta, 1996, p. 401). Furthermore, Rahman (2002, p. 123-124) pointed out a number of problems associated with the system approach and recommended that the best approach to estimate cost function is the single equation method. However, the present work applies the single equation approach.

3.5.4 Single equation approach to estimating cost frontier

The typical form of the single equation cost frontier model based on cross-sectional data is expressed as

$$C_i = g(y_i, p_i; \beta).exp(\xi_i + \tau_i)\ \xi_i + \tau_i = \varepsilon_i \text{ and } i = 1, 2, \ldots, n \qquad (3.51)$$

where, C_i indicates the observed cost incurred by the i-th farm *(i= 1, 2, 3, ...n)* and

$$C_i = p_i^T x_i = \sum_{i=1}^{n} . \sum_{j=1}^{M} p_{ji} x_{ji} \qquad ('M' \text{is the number of inputs})$$

p_i^T =price vector offered to the i-th farm

y_i= $(y_{1i}, y_{2i}, \ldots y_{\theta i}) \geq 0$; a $(1\times \theta)$ output vector produced by the i-th farm;

$p_i = (p_{1i}, p_{2i}, \ldots p_{Mi}) > 0$; a $(1\times M)$ vector of prices for used inputs offered to i-th farm;

β is a $(M\times 1)$ vector of unknown technology parameters to be estimated.

It is noteworthy that the inefficiency component, τ_i is added to the stochastic cost frontier, constructing the composed error, $\varepsilon = \xi_i + \tau_i$, unlike the stochastic production frontier, where the inefficiency component τ_i is deducted from the frontier. This is because of the fact that cost frontiers represent minimum costs, whereas production frontiers represent maximum outputs. The logic is that, due to the inefficiency effect, costs go up beyond the minimum level, whereas outputs fall short from the maximum level for the same reason; therefore, the inefficiency component (τ_i) is added in the former case and deducted in the latter case. Other specifications regarding the error terms, however, are the same as mentioned earlier (in section 2.3.4 of chapter 2).

With reference to the equation (3.51), the stochastic part, $g(y_i, p_i; \beta). exp(\xi_i)$, consists of the two components: the deterministic component, $g(y_i, p_i; \beta)$, which is common to all farms, and the farm-specific random component, $exp(\xi_i)$, which is assumed to take those effects which are beyond the control of the farm management into account (Kumbhakar and Lovell, 2000, p.137). Now the measure of cost/economic efficiency *(CE_i),* is the ratio of the minimum feasible cost in an environment defined by $exp\ (\xi_i)$ to the observed cost, i.e.,

$$CE_i \ = \frac{g(y_i, p_i; \beta). exp(\xi_i)}{g(y_i, p_i; \beta). exp(\xi_i + \tau_i)} = exp\ \{-\tau_i\} \tag{3.52}$$

Since $C_i \ \geq g(y_i, p_i; \beta). exp(\xi_i)$; the value of economic efficiency CE_i would be less than or equal to 1 (i.e., $CE_i \leq 1$). In addition, $CE_i = 1$, only when the inefficiency effect τ_i is zero, i.e., $C_i = g(y_i, p_i; \beta). exp(\xi_i)$; otherwise, $CE_i < 1$.

Assuming the single-output cost frontier, the log-linear Cobb-Douglas functional form of the equation (3.51) takes the form of

$$lnC_i = \ \beta_0 + \sum_{j=1}^{M} \beta_j\, ln\, p_{ji} + \ \beta_\theta \ln y_{\theta i} + \xi_i + \ \tau_i \tag{3.53}$$

This functional form has been used in the present study. However, a cost function should satisfy some essential properties, including i) non-negativity; ii) non-decreasing input prices; iii) non-decreasing outputs; iv) linear homogeneity in input prices; and v) concave input prices (Coelli et al., 2005, p. 23) (For detail, see Appendix 1).

Equation (3.53) holds the above properties if β_j s are non-negative and also comply with the constraints

$$\sum_{j=1}^{M} \beta_j = 1 \qquad (3.54)$$

Thus, prior to estimation, the cost frontier (here, equation 3.53) is reformulated to allow for neutral variations in the returns to scale parameter (Nerlove (1963) cited in Green, 1980, p. 49). Substitution of the constraint (3.54) in equation (3.53) would turn it into the homogeneity-constraint Cobb-Douglas cost frontier model (Coelli et al., 2005, p. 266). This process is actually carried out by dividing the total cost and input prices by a common input price, and it applies to the present analysis as well. Assuming that the *M-th* input price is used for this purpose i.e., to obtain a normalised equation (3.55), and it has M-1 input prices. Furthermore, if *M-1= m,* the normalised Cobb-Douglas cost frontier model looks like

$$\ln\left(\frac{C_i}{p_{M^{th}\,i}}\right) = \beta_0 + \sum_{j=1}^{m} \beta_j \, ln\left(\frac{p_{ji}}{p_{M^{th}i}}\right) + \beta_\theta \ln y_{\theta i} + \xi_i + \tau_i \qquad (3.55)$$

The price of the M^{th} input of the i-*th* farm has been used for normalisation; therefore, removing the *th*-term for notational simplicity means

$$\ln\left(\frac{C_i}{p_{Mi}}\right) = \beta_0 + \sum_{j=1}^{m} \beta_j \, ln\left(\frac{p_{ji}}{p_{Mi}}\right) + \beta_\theta \ln y_{\theta i} + \xi_i + \tau_i \qquad (3.56)$$

[Note: Hence, *(M×1)* vector of unknown parameters reduces to (m×*1)* vector of unknown parameters, since m = M-1]

According to equation (3.52), a measure of cost efficiency is given by

$$CE_i = exp\,(-\tau_i) \qquad (3.57)$$

An inefficiency model is incorporated in the stochastic cost frontier in a similar way to that in the stochastic production frontier. In addition, the same specification is assumed for the inefficiency model with the stochastic cost frontier. Thus, equation (3.18) is equally applicable to the cost frontier (3.56), and the present study complies with these procedures.

In fact, the estimation technique for the cost frontier model is exactly the same as that for the production frontier model because of the fact that the core parts of the two models are structurally the same (Coelli et al., 2005). A trivial difference between these two frontier models relates to the sign of the inefficiency error term τ_i and resulting skewness of the composed error. It looks like $\varepsilon_i = \xi_i - \tau_i$ in the production frontier model and $\varepsilon_i = \xi_i + \tau_i$ in the cost frontier model. For both models, the composed error term is asymmetric; however, for the production frontier, it is negatively skewed, while for the cost frontier it is positively skewed. Furthermore, for the cost frontier, a homogeneity restriction is imposed on the β-parameters. Apart from these two insignificant dissimilarities, the stochastic cost frontier models presented in equations (3.56) and/or (3.53) are structurally indistinguishable from the stochastic production frontier presented in equation (3.16) (Kumbhakar and Lovell, 2000). Accordingly, the analytical procedure explained for production frontier in section 3.3, is equally applicable to the estimation of a stochastic cost frontier. Likewise, the same distributional assumptions are considered against the error terms of the stochastic cost frontier if maximum likelihood methods are applied when estimating parameters. Moreover, farm-specific estimates of cost efficiency are obtained by putting the estimate of cost inefficiency component in the equation (3.57).

Therefore, if the model for inefficiency effects is combined with the stochastic cost frontier in equation (3.56)

$$\ln\left(\frac{C_i}{p_{Mi}}\right) = \beta_0 + \sum_{j=1}^{m} \beta_j \, ln \left(\frac{p_{ji}}{p_{Mi}}\right) + \beta_\theta \ln y_{\theta i} + \xi_i + \tau_i \qquad (3.58)$$

The measure of cost efficiency takes an identical form to that of equation (3.49) thus

$$CEi = exp\ (-\tau_i) = exp\ (-z_i\delta - \omega_i) \qquad (3.59)$$

However, the present work uses the ML method for estimating parameters and accordingly complies with the aforesaid procedures.

3.5.5 Predicting cost inefficiency

The cost efficiency of individual farms and overall cost efficiency is predicted following the same procedure as technical efficiency. The cost efficiency of the i-th farm is defined by $EE_i = exp\ (-\tau_i)$. Based on this result, the cost efficiency of an individual farm is predicted. With the same logic provided by Stevenson (1980), a truncated normal specification of the inefficiency component τ_i is assumed for this study as well. Accordingly, the conditional density of τ, given the composed error ε, is

$$f\left(\frac{\tau}{\varepsilon}\right) = \frac{1}{\sigma_c\sqrt{2\pi}} \cdot \frac{exp\left[-\frac{(\tau-\mu_c)^2}{2\sigma_c^2}\right]}{\left[\left(1-\Phi(-\frac{\mu_c}{\sigma_c}\right)\right]} \qquad (3.60)$$

where $\mu_c = \varepsilon\sigma^2_\tau + \mu\ \sigma^2_\xi / \sigma^2$ and $\sigma^2_c = \sigma^2_\tau\ \sigma^2_\xi / \sigma^2$. Either the mean or the mode of this conditional distribution $N^+ (\mu_c, \sigma^2_c)$ can be used as a point estimator of τ_i; however, the mean has been used for this calculation. The mean is given by

$$\hat{\tau_i} = E(\tau_i|\varepsilon_i) = \sigma_c\left[\frac{\mu_{ci}}{\sigma_c} + \frac{\varphi(-\mu_{ci}/\sigma_c)}{1-\Phi(-\mu_{ci}/\sigma_c)}\right] \qquad (3.61)$$

Once the point estimates of τ_i are obtained, the cost efficiency of an individual farm/producer can be predicted directly. Following the Battese and Coelli's (1988) formulation, the cost efficiency of i-th farm is calculated as

$$CE_i = E\,\{\exp(-\hat{\tau}_i)\,|\varepsilon_i\}$$

$$= \left[\frac{1-\Phi\left(-\frac{\mu_c}{\sigma_c}+\sigma_c\right)}{1-\Phi\left(-\frac{\mu_c}{\sigma_c}\right)}\right].\exp\left(-\mu_{ci}+\frac{\sigma_c^2}{2}\right) \quad (3.62)$$

The overall cost efficiency ($\widehat{CE}$) or mean efficiency, of all farms are obtained using the formula given below,

$$\widehat{CE} = \frac{1}{n}\sum_{i=1}^{n} CE_i \quad (3.63)$$

3.5.6 Statistical methods and software used in this analysis

This study mainly uses a well-established statistical procedure—the maximum likelihood (ML) method—to estimate the parameters. Estimates from the ordinary least square (OLS) method are also taken into consideration, and it helps to make a cross-check between the common estimates from both of the methods. Maximum likelihood determines the parameters in such a way that it maximises the likelihood (probability) of observed sample data (see Appendix 3), whilst OLS determines the parameters in such a way that it minimises the sum of the squared differences between the observed values and corresponding estimates (see Appendix 2). However, for the purposes of estimation and hypothesis tests, the study engages statistical software FRONTIER 4.1 and SPSS version 18 in collaboration with Microsoft Excel 10. According to Coelli (1996), the software programme FRONTIER 4.1 follows a three-step procedure to estimate the parameters. To being with, it provides OLS estimates of the parameters in the deterministic part of the whole model; these estimates are unbiased, except the intercept. This step is followed by a two-phase grid search for the adjustment of parameters. Then, the programme gives estimates of all the parameters, using OLS estimates as the starting point.

3.6 Dealing with Zero Observations in the Database

3.6.1 The reality of zero observations

The presence of zero observations against an input variable in the production process is not unusual in agricultural economics. In fact, it is a common phenomenon in developing country agriculture. Input variables may have zero values for several reasons. Some farmers in developing countries often skip one or more of the input items in growing their crops, either due to financial hardship, or unavailability of a particular input, or because of a perception that it would make little difference in the level of output etc. However, exclusion of the farmers who omitted any of the input items and confining the analysis to only those farmers having positive values for the input items is not an acceptable practice, because this would provide a misrepresentative picture of the reality. There are some procedures that are exploited to adjust the zero observations in estimating parameters with econometric models, but not all the procedures are statistically sound and give unbiased results. For example, zero values are often replaced by one or an arbitrary value that lies between one and zero. This practice is open to criticism in that it is not independent of measurement. Again, it is very likely that this procedure will result in biased estimates of parameters if the number of zero observations constitutes a significant proportion of total observations (Battese, 1997). This study, however, adopts a procedure that provides unbiased estimates; in fact, Battese (1997) is the proponent of this procedure. The next section describes the application of this procedure.

3.6.2 Adjusting zero observations: The Battese (1997) procedure

The Battese (1997) procedure can solve the zero observation problems in the data by using dummy variables that facilitate obtaining unbiased and efficient estimates. This procedure is the same as that used by Battese et al., (1996). This procedure can be explained with a Cobb-Douglas model in the following way. Suppose N number of farms produce a single product $'y'$ by two inputs, namely, X and Z. Equation (3.64) shows the general production relationship, where all farmers apply each input.

$$ln\, y_i = \alpha_0 + \alpha_1 \ln X_i + \alpha_2 \ln Z_i + \xi_i \qquad (i = 1, 2, \ldots N) \qquad (3.64)$$

In a changed situation, assume that some farmers do not apply Z input into their farms. Again, let an N_1 number of farmers use Z input; in contrast, an N_2 number of farmers do not use Z input. That means, an N_1 number of Z inputs have positive values, while an N_2 number of Z inputs have zero values. Equation (3.65) represents the first case, i.e., excludes those farmers who did not use Z input; while equation (3.66) depicts the second case, i.e., exclusion of those farmers who used Z input. These 'two inputs and one output' production relationships are given by

$$ln\, y_i = \alpha_0 + \alpha_1 \ln X_i + \alpha_2 \ln Z_i + \xi_i \qquad (i = 1, 2, \ . \ . \ . N_1) \qquad (3.65)$$

$$= \beta_0 + \alpha_1 \ln X_i + \xi_i \qquad (i = N_1 + 1, \ N_1 + 2, \ldots \ N_1 + N_2 = N) \qquad (3.66)$$

where ξ_i is statistical noise, assumed to be independent of explanatory variables and have a normal distribution with a mean of 0 and variance of σ^2. The unknown parameters $\alpha_0, \beta_0, \alpha_1, \alpha_2$ and σ^2 are to be estimated.

In equations (3.65) and (3.66), the output elasticity of X_i is the same for both the positive and zero values of Z_i; also, the variances of the error terms are equal, but the constant parameters (α_0 & β_0) are different (Battese, 1997). However, from the above equations (3.65) and (3.66), the parameters are estimated by pooling the data and the model is written as

$$ln\, y_i = \alpha_0 + (\beta_0 - \alpha_0) D_i + \alpha_1 \ln X_i + \alpha_2 \ln Z_i^* + \xi_i \, ; (i = 1, 2, 3, \ldots \ N) \quad (3.67)$$

where, D_i is the dummy for zero observations and it takes a value of 'one' if the observation is zero, and 'zero' if the observation is positive; symbolically,

$D_i = 1$, if $Z_i = 0$ and $D_i = 0$, if $Z_i > 0$; and $Z_i^* = \text{Max}\,(Z_i, D_i)$

From equation (3.67), it is clear that Z_i^*-variable takes either a 'positive value' or 'one'. More specifically, when Z-variable is positive, then Z_i^* takes its usual value, i.e., $Z_i^* = Z_i$; in contrast, when Z-variable has a zero value (i.e., in the case of zero observation), then $Z_i^* = 1$. Now the model (3.67) can efficiently estimate the parameters of the production function (3.65) and (3.66). This model, however, is extendable to more than one variable that has zero observations (Battese, 1997). In other words, zero observations are replaced by one and then a dummy variable is used for the incidence of zero observations. However, this method has already gained wider acceptance, because it provides unbiased estimates of the parameters and it has been used in many pioneer works, including Battese et al., (1993) and Battese and Coelli (1995).

3.7 Empirical Stochastic Frontier Models: An Overview

The comparative evaluation process of the two management systems SRM and TRM involves a number of models. These models are categorised into different groups based on their purpose and specifications. Primarily, there are two predominant models: one for the production frontier and another for the cost frontier. These models take the Cobb-Douglas functional form.

3.7.1 Functional forms and variants of the SFA model

As mentioned earlier (section 2.4 of chapter 2) that the Cobb-Douglas and the traslog are the most commonly used functional forms with stochastic frontier analysis. However, quality of data often plays a significant role in determining the right functional form between these two. For example, when data contains a considerable number of zero observations translog is not an appropriate functional form (Sharma, 1999; O'Neil and Matthews, 2001 and Sharma and Leung, 2002) as it generates more zero values which end up with biased estimates. This argument is equally applicable to the present study since a number of zero observations are present in the exogenous variables.

On the other hand, it is suggested that the impact of the functional form on key results of the study should be taken into consideration (Bravo-Ureta and Pinheiro, 1993) apart from hypothesis testing. Following this suggestions Conradie et al., (2006) estimated both the Cobb-Douglas and translog models in the study of efficiency for grape production with different production environments. The authors found that the translog model was adequate in some cases in terms of hypothesis testing; at the same time, comparing results from both of the models, the authors realised that the results from the Cobb-Douglas model were more consistent, which led them to accept the Cobb-Douglas model. Tadesse and Krisnamoorthy (1997) also acted upon Bravo-Ureta and Pinheiro's (1993) suggestion; the authors checked it with the translog functional form and observed low t-ratios for all input variables in the model, while the constant term was highly significant. The authors then switched to a Cobb-Douglas functional form for estimating the parameters. Taking the recommendation of Bravo-Ureta and Pinheiro (1993, p.97) into consideration and then following the empirical works of Conradie et al., (2006) and Tadesse and Krisnamoorthy (1997), the present study estimates the stochastic frontier models using both Cobb-Douglas and traslog functional forms before selecting the appropriate functional form. However, it is observed that the Cobb-Douglas functional form provides more consistent results and thus it (C-D model) is accepted as the functional form of the stochastic frontier analysis of the present study.

The general functional forms of the Cobb-Douglas and translog functional forms used for the production and cost frontiers are presented below.

The Cobb-Douglas production frontier:

$$\ln y_i = \beta_0 + \sum_{j=1}^{m} \beta_j \ln x_j + \xi_i - \tau_i \qquad (3.68)$$

The translog production frontier:

$$In\, y_i = \beta_0 + \sum_{j=1}^{m} \beta_j \, ln\, x_j + \frac{1}{2}\sum_{j=1}^{m}\sum_{m=1}^{j} \beta_{mj} \, ln\, x_m \, ln\, x_j + \xi_i - \tau_i \qquad (3.69)$$

where

y_i refers to total output of the i-th farm

x_j indicates an independent variable

m is the number of independent variables

β_0, β_j's and β_{mj}'s are unknown parameters; for interaction terms $\beta_{mj} = \beta_{jm}$ for all m and j; and the error terms ξ_i and τ_i refer to statistical noise and inefficiency effects respectively.

The Cobb-Douglas function is a special case of translog function; in fact, it is nested to the transcendental logarithmic functional form. When the effect of interaction terms, including square terms, are equal to zero, (i.e., $\beta_{mj} = 0$, for all *m, j =1,2, ... , m,* and *m*-th term ≠ *j*-th term) the translog functional form collapses to the Cobb-Douglas form.

On the other hand, the cost frontiers for both of the management systems are similar and presented below.

The Cobb-Douglas cost frontier:

$$\ln c_i = \alpha_0 + \ln y_i + \sum_{j=1}^{m} \alpha_j \ln x_j + \xi_i + \tau_i \quad (3.70)$$

The translog cost frontier:

$$In\ c_i = \alpha_0 + \ln y_i + \sum_{j=1}^{m} \alpha_j\, ln\, x_j + \frac{1}{2}\sum_{j=1}^{m}\sum_{m=1}^{j} \alpha_{mj}\, ln\, x_m\, ln\, x_j + \xi_i + \tau_i \quad (3.71)$$

where

c_i refers to total cost of production for the i-th farm

x_j indicates an independent variable

m is the number of independent variables

α_0, α_j's and α_{mj}'s are unknown parameters; for interaction terms $\alpha_{mj} = \alpha_{jm}$ for all *m* and *j*; and the error terms ξ_i and τ_i are same as specified earlier.

The functional/structural form of the inefficiency effect model is the same for both of the production and cost frontiers as well as the Cobb-Douglas and translog models. The model for inefficiency effects is given by

$$\tau_i = \delta_0 + \sum_{j=1}^{k} \delta_j z_j + \omega_i \quad (3.72)$$

where, τ_i refers to inefficiency effect of the i-th farm

z_j indicates a farm- and management-specific variable

k is the number of farm- and management-specific variables

δ_0, δ_j's and α_{mj}'s are unknown parameters and ω_i is an error term for the inefficiency model.

Several variant models can be developed from each of the frontier models based on the state of existence of inefficiency effect as well as distributional specifications of the inefficiency effect model. In this study, four types of variant models are developed that are relevant to this study and tested with the likelihood ratio (LR) for selecting the appropriate model for this analysis. General discussions about the variant models and LR test are presented in section 3.9. Again, for the sake of convenience and clarity two separate chapters are used for analysing these models; chapter 5 for the stochastic production frontier (SPF) models and chapter 6 for the stochastic cost frontier (SCF) models.

3.8. Yardsticks of Productivity for Performance Measurement

3.8.1 Yardsticks of productivity in agriculture

In addition to efficiency estimation involving econometric models, this study engages some other yardsticks of productivity that are directly related to the performance of production units. Productivity in agriculture is assessed using some practical measurements, including 'yield-gap', 'cost-gap' and input usage costs. Furthermore, 'potential yield increment' and 'potential cost saving' are good indicators of production units' performance and these are computed from yield-gap and cost-gap measures respectively. 'Yield-gap' relates to the production frontier and is applied to measure the extent of slackness in production; whilst, 'cost-gap' (or more specifically 'excess cost') relates to the cost frontier and is used to gauge the extent to which farms incur excess costs in the production process. Accordingly, yield-gap in this analysis relates to paddy production and cost-gap to fisheries production. Meanwhile, input usage cost applies to the production function and is assessed for paddy production only. In addition to these three basic measurements, two variant measurements, namely, potential yield increment (PYI) and potential cost saving (PCS) are taken into consideration with reference to yield-gap and cost-gap respectively.

3.8.2 Measurements of yield-gap and cost-gap

As mentioned earlier (section 2.7 of chapter 2), yield-gaps are calculated by the mathematical difference between yield potential and actual farm-level yield. Thus, the generalised and simplified formula for a yield-gap is given by

$$Yield\ gap\ = \frac{Potential\ yield - Actual\ yield}{Area\ of\ land}$$

Symbolically,

$$Y_a = \left[Y_f - \ Y_a\right]/L \qquad (3.73)$$

On the other hand, a cost-gap is determined as the mathematical difference between potential cost and farm-level cost in a specified spatial and/or temporal state. Potential cost refers to the minimum possible cost in a specific production environment and it is very likely that it would vary with different production environments because of their different input usage patterns. Thus different production environments may cause different levels of potential cost. The generalised and simplified formula for cost-gap is expressed as

$$Cost\ gap\ = \frac{Actual\ Cost - Potential\ Cost}{Area\ of\ land}$$

Symbolically,

$$C_a = \left[C_f - \ C_a\right]/L \qquad (3.74)$$

Meanwhile, standardised formulae are developed in order to measure potential yield and cost (see sections 7.2 and 7.3 of chapter 7). Potential yield increment (PYI) and potential cost saving (PCS) are derived from yield-gap and cost-gap respectively, where PYI refers to the additional output that could be produced if a farm is technically efficient, and PCS refers to an amount of cost that could be saved if a farm is economically/cost efficient. However, the data for the above yardsticks are processed using the software SPSS 18, in collaboration with Microsoft Excel 2010.

3.9 Hypotheses Tests and Decision Rules

3.9.1 General discussions

Hypothesis testing is one of the two integral parts of statistical inference in classical statistics. The other part is 'estimation', which is the core part of any empirical research. An elaborate discussion on estimation has been made in the above sections, and this section devotes to the discussion on hypothesis testing. Needless to say, hypothesis testing comes after estimation in order to make a judgment on estimation with reference to the unknown aspects of the population based on sample information. These unknown aspects usually consider the characteristics of the population, including the parameters of the population, the functional form of the parent distribution and even the functional form of the sample data. There are a number of hypotheses tests involving different types of test statistics for judging different types of population characteristics. A sample is amenable to hypothesis tests if it satisfies either of the two basic criteria: (i) sample data follow a distribution or (ii) the size of the sample is large enough. The second criterion applies to hypothesis testing relating to the stochastic frontier model since the composed error of the model does not follow any systematic distributional specification. This is why the t- and F-tests concerning stochastic frontier analysis are only asymptotically justified; however, these tests are applied to a small sample if the error terms are normally distributed and parameters are linear. The other tests that apply to stochastic frontier analysis, e.g., likelihood ratio (LR), Wald, and Lagrange Multiplier (LM) are originally asymptotically justified, i.e., we can use them if the sample size is large (Coelli et al., 2005, p. 225, 258).

The Wald and likelihood ratio tests are well known among the alternative hypothesis tests regarding stochastic frontier analysis. Calculation of the Wald statistic is much simpler than the likelihood ratio statistic due to the fact that it does not require estimating both models under null and alternative hypotheses. However, the performance of the Wald test is poor compared to the LR test. So, the Wald test has been eclipsed by the LR test over time due to the ease of estimating ML estimates in particular.

In the stochastic frontier analysis, a significant share of hypothesis testing relates to restricted and unrestricted models and these tests are preferably carried out by the likelihood ratio (LR) test. The underlying idea of the *likelihood ratio test* is that, if the restrictions are true, the maximised value of the likelihood function with the imposed restrictions will be close to the maximised value of the likelihood function without the imposition of restrictions (Kmenta, 1986, p. 491). The maximum log-likelihood functions for restricted and unrestricted models are respectively L $(\widehat{\beta}, \widehat{\sigma^2})$ and L $(\underline{\beta}, \underline{\sigma^2})$. Then, asymptotically

$$\text{LR statistic} = -2\,\{ L(\widehat{\beta}, \widehat{\sigma^2}) - L(\underline{\beta}, \underline{\sigma^2})\} \sim \chi^2_r \qquad (3.75)$$

where, '*r*' is the number of restrictions, which is calculated by deducting the number of restricted coefficients from the number of unrestricted coefficients. In hypothesis testing, the restricted model is considered under the null hypothesis and the unrestricted model under the alternative hypothesis. In the LR test, both restricted and unrestricted models are estimated, unlike the Wald, and Lagrange Multiplier (LM) tests (Coelli et al., 2005, p. 225). A measure of the closeness between the log of the maximised likelihood values for the restricted model and those for the unrestricted model is the likelihood ratio statistic. Thus, the generalized likelihood ratio test statistic, λ, is calculated as

$$\lambda = -2\,[\ln \{L(H_0)\} - \ln \{L(H_1)\}] \qquad \sim \chi^2_r \qquad (3.76)$$

where $L(H_0)$ and $L(H_1)$ denote the values of log-likelihood functions under the null and alternative hypotheses respectively. As mentioned earlier, the null hypothesis is based on the restricted model, but the alternative hypothesis may be on either an unrestricted or relatively less restricted model. However, the test statistic is assumed to be asymptotically distributed as a chi-square random variable with degrees of freedom equal to the number of restrictions involved.

The most common hypothesis tests associated with stochastic frontier analysis are

i) testing absence or presence of inefficiency effects;

ii) randomness test: whether inefficiency effects are random;

iii) truncated normality test: whether the individual effect of each inefficiency variable is zero; i.e., the model is a variant of Stevenson's (1980) specification; and

iv) half normality test: whether the intercept and the coefficients of all inefficiency variables are zero; i.e., the model is a variant of the Aigner et al., (1977) specification.

Stochastic frontier analysis can be carried out with production, cost, revenue and profit functions, involving both cross-sectional and panel data. However, the same principle of hypothesis testing applies to these analyses as far as the estimation of an inefficiency effect model is concerned; only the specification for restriction(s) differs. The next section presents a discussion of hypothesis testing, where illustrations relate to the stochastic production frontier with cross-sectional data, and most part of this discussion applies to the present study as well.

3.9.2 Whether inefficiency effect is absent or present

Whether inefficiency effects exist or not is a common issue in the stochastic frontier analysis because the answer to this question relates to the justification of the study. Formal statements of this test against the null hypothesis and the alternative hypothesis are given by

H_0: no technical inefficiency exists (i.e., $\gamma = 0$) (3.77)

H_1: technical inefficiency exists (i.e., $\gamma > 0$)

(The γ-parameter represents the variance of the inefficiency effect, σ^2_τ, as per the parameterisation in equation 3.48).

As mentioned above (in equation, 3.76), the likelihood ratio statistic, λ, usually assumes asymptotic chi-square distribution, but there is an exception to this when the null hypothesis of the test assumes $\gamma = 0$. This is because of the fact that the position of this null hypothesis is on the boundary of the parameter space, as γ cannot take a value of less than zero (Coelli, 1995a). Furthermore, take γ assumes a value of less than zero, this means that the variance of inefficiency effects, σ^2_τ, is negative, which is absurd. So, instead of assuming asymptotic chi-square distribution, the likelihood ratio statistic, λ, assumes asymptotically distributed mixed chi-square distributions, (1/2) χ^2_0 + (1/2) χ^2_1, with one degree of freedom (Coelli, 1993 and 1995a). The alternative hypothesis of the test is, H_1: $\gamma > 0$, since γ cannot be less than zero. The critical value of this one-sided likelihood ratio test at α level of significance of the χ^2_1-distribution is equal to the critical value of a two-sided (standard) test at the 2α level of significance. Accordingly, the decision rule applies to rejecting the null hypothesis that the likelihood ratio (LR) is greater than χ^2_1 (2α) for a test of size α.

(i) A variant of this test

The above hypothesis test applies to the model proposed by Aigner et al., (1977). However, this test can be applied to the variants of Aigner et al., (1977) model (e.g., for panel data) and other models by extending the single restriction hypothesis to multiple restrictions. For example, the model suggested by Stevenson (1980) assumes truncated normal distribution for inefficiency effects, τ_i, and thus the test of the hypothesis that there is no technical inefficiency would involve a test of a joint hypothesis, setting two parameters (γ and μ_τ) equal to zero; here, μ_τ is the mean of the inefficiency effect. However, the null and alternative hypotheses are given by

H_0: no technical inefficiency exists (3.78)

(i.e., $\gamma = \mu_\tau = 0$)

H_1: technical inefficiency exists

(i.e., $\gamma > 0$; $\mu_\tau \neq 0$)

Since $\gamma = 0$ is associated with the test, the likelihood ratio statistics would not be as asymptotically distributed as chi-square distribution (χ^2_2), but rather would assume a distribution equal to a mixture of chi-square distributions [(1/4) χ^2_0 + (1/2) χ^2_1 + (1/4) χ^2_2] with two degrees of freedom (Coelli, 1995a).

The above hypotheses tests apply to an error component model; more specifically, to the stochastic frontier function of the 'Battese and Coelli (1992)' specification and its variants, (details of the variant models that are obtained through the imposition of restriction(s) can be found in Coelli, (1996)). However, in the case of the technical effect model, i.e., the inefficiency frontier model proposed by Battese and Coelli

(1995), the null hypothesis that 'there is no technical inefficiency' takes on different specifications in terms of the restrictions to be imposed. This modification is due to the incorporation of inefficiency variables in the system (as specified in equation 3.18) where these variables are assumed to be responsible for the inefficiency effects. It is assumed that the technical inefficiency effects, τ_i, are an independent, non-negative truncation of normal distribution with means of $z_i\delta$ $(i= 1, 2, 3, \ldots k)$ and unknown variance σ_τ^2. Thus, the means may vary for different farms but the variances are assumed to be the same (Battese and Broca 1997).

The statement and specifications of the null hypothesis that 'there is no technical inefficiency' for the alternative hypothesis are presented by

H_0: no technical inefficiency exists (3.79)

(i.e., $\gamma = \delta_i = 0; i= 0, 1, 2, 3, \ldots k$)

H_1: technical inefficiency exists

(i.e., $\gamma > 0; \delta_i \neq 0;$) $(i= 0, 1, 2, 3, \ldots k)$

If the null hypothesis is not rejected, this will indicate that the traditional average response model (OLS estimation) is an adequate representation to the data. Even the standard stochastic error component model is beyond consideration for the half normal distribution of the technical inefficiency effects, since the error component is worth removing. As a result, the technical inefficiency effect, τ_i, is removed from the stochastic frontier model (Legune and Sharma, 1999).

3.9.3 Whether inefficiency effect is stochastic or not

Inefficiency effects are non-stochastic, meaning $\gamma = 0$. If the parameter, γ is zero, the variance of the inefficiency effects (σ_τ^2) will also be zero (since $\gamma = \sigma_\tau^2 / \sigma_\tau^2 + \sigma_\xi^2$). As per statistical methods, zero variance of inefficiency effects indicates that inefficiency effects are constant, meaning the combined effects of all inefficiency explanatory variables exert the same level of inefficiency effect on each farm. If such a condition exists, it does not make sense to measure inefficiency because each farm experiences the same inefficiency effect. This means the model collapses into the error component model of Aigner et al., (1977), in which the mean inefficiency effect represented by δ_0, is zero.

However, the null hypothesis and the alternative hypothesis of this test are

H_0: inefficiency effects are non-stochastic (3.80)
(i.e., $\gamma = \delta_0 = 0$)
H_1: inefficiency effects are stochastic
(i.e., $\gamma > 0; \delta_0 \neq 0$)

Acceptance of the null hypothesis means a constant level of inefficiency effects prevails across farms. This situation is well represented by a traditional mean response function in which the inefficiency variables are included as ordinary explanatory variables (Battese and Coelli, 1995; Sharma and Leung, 1999).

It is worth noting that the hypotheses tests in both equations (3.78) and (3.80) involve the γ-parameter and, thus, it seems that they are similar; however, in reality, they are not, because the γ-parameter associated with the 'Battese and Coelli (1995)' model is not the same as that associated with the 'Battese and Coelli (1992)' model (see Battese and Broca, 1997). In fact, the γ-parameter in Battese and Coelli's (1995) model represents the combined effects of different groups of variables.

3.9.4 Truncated normality test for inefficiency effect

When it is assumed that the model for the inefficiency effect in a stochastic frontier has truncated normal distribution, this test examines if each of the inefficiency variables has contributed to the mean of the truncated normal distribution. The null hypothesis of this test states that the coefficients of all the explanatory variables in the inefficiency model are zero, meaning the technical inefficiency model follows the same truncated normal distribution, with a mean equal to δ_0, as in the error component model. That means the inefficiency effects are not significantly influenced by the explanatory variables in the inefficiency model (Coelli and Battese, 1996; Sharma and Leung, 1999). In other words, inefficiency effects are not a linear function of the farm-specific inefficiency variables. Here, statements for the null and alternative hypotheses are given by

H_0: individual effects of all the inefficiency variables are zero (3.81)

(i.e., $\delta_i = 0$; $i= 1, 2, ...k$)

H_1: individual effects of all inefficiency variables are not zero

(i.e., $\delta_i \neq 0$; $i= 1, 2, ...k$)

Rejection of the null hypothesis indicates that joint effect of the inefficiency variables on the inefficiency of the production/cost minimisation/profit maximisation is significant, although the individual effects of one or more of the variables may be statistically insignificant (Battese and Coelli, 1995). On the other hand, acceptance of the null hypothesis signifies that technical inefficiency effects follow the truncated-normal distribution of the Stevenson (1980) specification. Nevertheless, the standard stochastic error component model is not appropriate for the truncated normal distribution of the technical inefficiency effects (Legune and Sharma, 1999).

3.9.5 Half normality test for inefficiency effect

This test relates to exploring appropriate distributional specifications for the inefficiency component in the stochastic frontier model. It is well known that, prior to maximum likelihood estimation, it is necessary to assume a distributional specification of the variable. For the inefficiency component, the most commonly used types of distribution are half normal and truncated normal; however, it is necessary to determine which of these two types is appropriate for a given data set. Hence, the half normality test is carried out for this purpose. The null hypothesis of the half normality test specifies that the intercept, as well as all the coefficients of the farm-specific inefficiency variables, are zero. That means the technical inefficiency effects have a traditional half-normal distribution with a mean equal to zero, so the stochastic frontier model becomes identical to a model originally proposed by Aigner et al., (1977). In fact, this test leads to making a choice between half normal and truncated normal distribution for the inefficiency component. Accordingly, the test leads to the following statements for the null and alternative hypotheses.

H_0: the inefficiency model follows half normal distribution (3.82)

(i.e., $\delta i = 0$; $i = 0, 1, 2, \ldots k$)

H_1: the inefficiency model follows truncated normal distribution

(i.e., $\delta i \neq 0$; $i=0, 1, 2, \ldots k$)

Rejection of the null hypothesis indicates that the intercept and all coefficients of the inefficiency variables are not zero, which justifies the incorporation of the model for the inefficiency effects in the stochastic frontier function. Acceptance of the null hypothesis signifies that not a single element of the inefficiency variables has significantly influenced the inefficiency effects, even though a standard stochastic error component model is not an adequate representation for the half-normal distribution of the technical inefficiency effects (Sharma and Leung, 1999).

3.9.6 Test for an appropriate functional form

Selection of a functional form is crucial in every empirical study because an inappropriate functional form may lead to misleading conclusions[4]. The most commonly used functional forms in the stochastic frontier analysis are Cobb-Douglas and translog. These two forms are referred to as a restricted model and unrestricted model respectively; however, they are subject to test on the grounds of appropriateness for a particular data set. By estimating both functions and substituting the likelihood functions in the equation (3.76), acceptance of imposed restrictions is tested, which in turn gives an indication of the appropriate functional form. Hence, the null hypothesis (H_0) is constructed against the alternative hypothesis (H_1) as

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[4]In selecting the functional form, a test of appropriateness in terms of imposed restrictions is usually given more importance. However, test results may not reflect the true picture of the data set when the data contain a good number of zero observations. For example, data in developing country agriculture often contains zero observations but the incidence of zero observations is rare in developed country agriculture.

H_0: Cobb-Douglas function is appropriate (3.83)

H_1: Translog function is appropriate

If the null hypothesis is accepted, then translog is not an adequate representation of the sample data set.

3.10 Data Collection: Principles and Techniques

3.10.1 Outline of data collection

Methods of data collection is a vital element of research methodology in the production of knowledge. There are different methods of data collection e.g., observations, documents, questionnaire survey by telephoning or online, face-to-face interviewing etc. The most powerful way of gathering data for a research is face-to-face interviewing. Based on the degree of control exercised by the researcher over the nature of the response and the length of the answers allowed to the respondent there are three types of interview format: structured, semi-structured or unstructured. However, considering the nature of this empirical study, it is envisaged that a structured questionnaire survey with face-to-face interviewing the respondents/households selected through a probabilistic sampling method is appropriate for the present study. It is to mention that during the data collection it is obligatory to maintain ethical considerations in full scale, and this study is no exception to this. In sum, the present study collected data through structured questionnaire survey selecting the interviewees (i.e., farmers involved in paddy and fisheries production) by multistage probability sampling while maintaining the ethical principles in tandem.

3.10.2 Methods applied to ensure probabilistic sampling

The study area has two parts and both parts are characterised as tidal mudflat. One part is called beel Dakatia and the other part is beel Bhaina, where the two FCDM systems are operational in order to protect agriculture from flooding and waterlogging hazards. Flooding and waterlogging hazards are such that they take a solar year to complete a full cycle, particularly in Bangladesh; so, it is essential to consider a year-round phenomena to evaluate the FCDM systems. This entails including both of the two dominant crops, paddy and fisheries, produced throughout the year with the management systems. Accordingly, two set of questionnaires, one for paddy and one for fisheries, are designed to collect data from the household sample survey. Before designing the questionnaires a good number of formal and informal meetings and focus group discussions (FCDs) are arranged to get familiar with the farming practices of the areas and related issues. From these meetings and discussions, it was clear that stratified sampling is useful here and it is put into practice. In fact, stratification improves the representativeness of the estimates (Warwick and Lininger, 1975, p. 75). In the sampling procedures, the principles of proportionality with stratification (where applicable) are applied for a representative number of samples from each study area. Elevations of beel bed and sizes of farm households are the obvious reasons that motivated us to adopt stratified sampling.

The bed of each beel is not with the same elevation since it has passed through different hydrological regimes. Considering this issue, each beel is divided into two parts—the upland and the lowland—with a view to obtaining a representative data. A good number of villages are randomly selected from both of the upland and lowland parts of each beel in proportion to the area of each part. Farm households for each sampled village are then stratified into small, medium and large groups based on land holdings and then the proportionate number of households are chosen from each stratum for the interview. A face-to-face interviewing technique is often used by researchers for empirical studies (see Von Baily et al., 1989; Wilson et al., 2001; Wadud and White 2002), and this study also adopts this technique to collect primary data.

3.11 Summary and Conclusions

The concept of frontier analysis is fully consistent with the neoclassical theory of production (unlike the average analysis); while as an analytical tool, the stochastic frontier analysis (SFA) satisfies both economic and statistical standards. Indeed, SFA is a robust and sophisticated analytical tool and it is widely used in estimating the productive efficiency of production units/organisations. Needless to say, it took SFA more than three decades to attain the present sophisticated state from a trivial one.

SFA is very flexible in many ways, including the distributional specifications of its inefficiency effect model, the functional forms it assumes, the statistical methods it takes for estimation of parameters and so on. However, among the alternatives this study selects a specification, a functional form and a statistical method that provides unbiased and efficient estimates/results and at the same time is consistent with underlying theories, assumptions and the circumstances. For instance, in terms of estimating inefficiency effects either a single-stage or a two-stage procedure can be applied; the former complies with the underlying assumption and has been followed in this study. Again, the error term for inefficiency effect can take any of the four distributional assumptions, and this study entertains two widely used assumptions, namely, the half normal and the truncated normal, in order to select the better fit.

Turning to statistical method, the maximum likelihood (ML) method appears to be the appropriate one in estimating econometric models with SFA. On the other hand, among the alternative approaches to deal with zero observations, the dummy variable approach provides the most unbiased estimates, because it is statistically consistent, and the present analysis applies this approach. In addition to technical and cost efficiencies, this work considers some yardsticks of productivity (e.g., yield-gap, cost-gap etc.) in its pursuit of performance evaluation. In measuring these yardsticks, standard formulae are developed and the data in these regards are processed using the software SPSS 18, in collaboration with Microsoft Excel 2010.

The aforementioned flexibilities are subject to hypothesis testing, and the study exploits hypotheses testing as required including the likelihood ratio (LR) test. For primary data, the present study adopts a probability sampling approach, involving stratified random sampling, simple random sampling and multistage sampling techniques in order to collect representative sample observations. A face-to-face interviewing is followed using structured questionnaires, and hence, ethical codes are fully maintained throughout.

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CHAPTER FOUR
STUDY AREA AND DATA COLLECTION

Chapter Structure

Chapter FOUR

Study Area and Data Collection

Objectives and Organisation of the Chapter

There are two objectives of this chapter: firstly, to portray the specific characteristics of the study area that affect agricultural productivity; secondly, to introduce the techniques used to conduct farm household survey for collecting primary data on paddy and fisheries production. Sampling techniques for farm household survey was designed considering the topographic features of the study area. This is one of the main reasons for placing these two parts in a chapter. However, the first section points out the importance of topographical information for collecting representative data for studies relating to agricultural productivity. Section two presents a discussion on wetland types and identifies the wetland type of the study area as a whole. The next two sections describe the topography and hydrology of the study area. Agricultural practices in the gher-farming environment of the study area are highlighted in section five. Sections six to eight state the sampling techniques applied to collecting primary data from household survey, while section nine reports the shortcomings of the sample survey and the strategies adopted to overcome them. Finally, section ten presents the summary and conclusions.

4.1 Introduction

This study undertakes a comparative analysis of two competing flood control and drainage management (FCDM) systems that were implemented in two areas located within the Khulna-Jessore Drainage and Rehabilitation Project (KJDRP). The KJDRP is spread over parts of the Khulna and Jessore districts in the southwest coastal region of Bangladesh, as shown in map 4.1. Both parts of the study area are actually reclaimed and/or converted wetland areas, where the competing FCDM systems were implemented in order to protect crops from flooding and then to increase agricultural productivity. Here, it is important to identify what kind of wetlands they are from the view point of topography. This would help better understand some of the issues, including the research problem, research design and goals of this study. It is recommended to know topography of the study area to ensure a representative sampling frame, particularly in agriculture, because agricultural productivity is likely to differ according to changes in the topographic setup. Cognizance of topography of the study area helps design the sampling techniques and choose appropriate methods for data manipulation.

4.2 Classifying the Study Area by Wetland Type

Classification of wetlands, in terms of their physical and functional features, is necessary when they are assessed from the standpoint of agricultural productivity. This is because of the fact that soil quality and hydrology play important role in determining productivity in agriculture and these two factors vary with wetland types. There are other reasons that justify identification of a wetland by type as well. For example, a wetland is often called by several names in the English language, which may cause confusion; so, it is better to provide enough information about a wetland in consideration in order to avoid any such confusion. As Keddy (2010, p. 5) states,

> “. . . the terminology for describing wetlands varies both among human societies, and among their scientific communities. Thus one finds an abundance of words used to describe wetlands—bog, bayou, carr, fen, flark, hochmoor, lagg, marsh, mire, muskeg, swamp, pocosin, pothole, quagmire, savannah, slob, slough, swale, turlough, yazoo—in the English language alone”.

For example, in the United States, forested wetlands are usually termed *swamp,* whereas in Europe, the term *reed swamp* is often used in relation to a kind of freshwater marsh covered mostly with *Phragmites* spp. (Mitsch and Goesselink, 2000, p. 378).

Wetland type varies primarily with its location, habitat function, the salinity level of the water, soil type and appearance. The high variability of conditions makes it difficult to distinguish between different types of wetland. Many ecologists have defined wetlands as perceived them. Wetlands are, in fact, entangled with definitions; this is because of the great diversity of wetlands and also the difficulty in demarcation of wetlands when several varieties of wetland lie along a continuum. From a technical point of view, Keddy (2010, p. 2) defines, "a wetland is an ecosystem that arises when inundation by water produces soils dominated by anaerobic processes, which, in turn, forces the biota, particularly rooted plants, to adapt to flooding").

A widely accepted wetland definition was given by Cawardin et al. (1979) for the US Fish and Wildlife Service. According to Cawardinet al., (1979, p. 3),

> "Wetlands lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year".

However, the definition given by the Ramsar Convention (1971, p. 7) is most commonly used by researchers. In fact, the Ramsar Convention's (1971) definition of wetlands is more comprehensive. It is expressed in two parts (as reported under articles 1.1 and 2.1 of the Convention):

> Article 1.1: "...[wetlands are] areas of marsh, fen and peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres."
>
> Article 2.1: "[Wetlands] may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands."

According to the Ramsar classification, wetlands are of three types: Marine/coastal wetlands, inland wetlands and human-made wetlands. Among the coastal and inland wetlands, the four dominant types are marsh, swamp, bog and fen. Intuitively, the study area may fall into the broad category of marsh wetland. However, before identifying the association of the study area with wetland types, it is necessary to have an overall account of all major types of wetlands.

(i) Bogs and fens

Bogs and fens are peat deposits and distributed mostly in the cool bread zones of the northern hemisphere where excess moisture is abundant because of less evapotranspiration than precipitation. Most bogs and fens are found in westerns Siberia, Alaska, Canada, Scandinavia and Eastern Europe. Bogs get water mostly from rain or snow, and do not have significant inflow or outflow of surface water or groundwater (Mitsch and Goesselink, 2000, p. 420). Thus water in bogs is low in oxygen and very acidic which support acid loving vegetation, particularly mosses. Cool/boreal environment and low oxygen level in bogs make quick decomposition of dead plants more difficult for microorganisms, which lead forming peat soil; soil and water become very acidic due to slow pace of decomposition. It is noteworthy here that bogs are also called *mire* and *quagmire*. Turning to fens, they are characterised as open peatland system in that they have greater water exchange. Fens get water supply from surrounding mineral soils. So, water in fens is less acidic and richer in nutrients compared to bogs, and this kind of water support grasses and reeds. In fact, fens and bogs are close cousins and they often occur nearby; it is not unusual if a fen becomes a bog over time (Mitsch and Goesselink, 2000, p. 420).

Bogs and fens are often termed as peatlands because of their peat deposits. However, wetlands with peat deposits are also found in warm temperate, subtropical or tropical zones and these wetlands are called pocosins. The term pocosin is taken from an Algonquin Indian word meaning 'swamp-on-hill', and is commonly represented as evergreen shrub bogs (Tooker, (1899), cited in Richardson 1983, p. 626). As the name suggests they receive moisture only from precipitations. Pocosins mostly occur in the

Southeastern Coastal Plain of the United States, from Virginia to Florida (Mitsch and Goesselink, 2000, p. 420).

(ii) Swamps

Swamps are forested wetlands. Swamps may occur along large rivers (Girel et al., 2003, p. 8) or on the shore of large lakes (Wilcox et al., 2007), or on the estuaries like the Sundarbans in Bangladesh. Swamps generally refer to mangrove swamps. Mangrove swamps occur in the tropical and subtropical coastal zones in the world ranging between 25^0 N and 25^0 S latitude (Mitsch and Goesselink, 2000, p. 336). Based on hydrodynamic features mangroves are classified into four major types as suggested by Cintron et al., (1985). These are, (a) fringe mangrove, including over-wash island (b) riverine mangroves (c) basin mangrove and (d) dwarf (or scrub) mangrove. The study area, however, is influenced by riverine mangrove. Riverine mangrove forests are a kind of floodplains that occur along the coastal tidal rivers and channels. These wetlands can extend several miles inland from the coast. Upstream flows play an important role in maintaining the ecology of the riverine mangrove wetlands through salinity control, sedimentation and nutrient exchange. Freshwater runoff from uplands combined with terrestrial and fluvial nutrients and diurnal tidal flashes make these wetlands very productive to grow tall trees ranging from 16 to 26 meters (Mitsch and Goesselink, 2000, p. 343).

(iii) Marsh

As mentioned earlier that the study area belongs to the broad category of marsh wetland. Marsh wetlands can be divided into several groups in terms of location, tidal influence and salinity level. The major types of marsh wetlands are inland marshes, salt marshes and freshwater tidal marshes. According to Ramsar classification the two important categories of wetland types are marine/coastal wetland and inland wetland. Needless to say, the study area belongs to coastal wetlands, so it is not an inland marsh. Salt marshes occur in the middle and high latitudes along coastlines across the world. Tidal flooding frequency and duration, soil salinity, soil permeability and nutrient variation are considered to be the major factors that determine the structure and function of salt marshes. In tropical and subtropical regions, more specifically between 25^0 N and 25^0 S, salt marshes are replaced by mangrove swamps (Odum, 1988; Mitsch and Goesselink, 2000, p. 262). Mangrove forest the Sundarbans, in Bangladesh, is an example of this salt-marsh replacement in the subtropics region and the study area is located to the north of the Sundarbans. Thus, it can be said that the study area falls into the tidal freshwater marsh wetland.

Tidal freshwater marshes are found along the dynamic shores of coastal rivers which are subject to regular diurnal tidal flooding. For example, freshwater marshes are seen to occur with the Delaware, Hudson, Potomac and St. Lawrence River systems in North America; the Rhine and Thames in Europe; and the Ganges and Yellow Rivers in Asia (Odum, 1988, p. 150). Freshwater wetlands remain the reach of oceanic salt water although they are not close enough to coasts. The physical conditions of tidal freshwater marshes are maintained by interaction between adequate run off or (freshwater) upstream river flow and significant range tidal influence. Indeed, freshwater conditions may have low concentrations of salt. According to Odum (1988), the average annual salinity is below 0.5 ppt (i.e., 0.5g of salt in one litre of water). However, the degree of concentration increases in the dry season (i.e. less or no precipitation season), during spring tides, and in the event of unusually low river discharge. These marshes may assume more of the characteristics of inland marshes as the tidal influence attenuates further upstream, and this change makes it difficult to distinguish between inland and tidal freshwater marshes when they form a continuum (Mitsch and Goesselink, 2000, p. 307). Tidal marshes are very vulnerable to variable ranges of flooding. Besides normal tidal flooding, tidal marshes experience an unpredictably high magnitude of flooding when tides are reinforced by rain and wind, inundating areas that are normally spared from normal tides (Greenberg, 2006). However, drawing on the above discussions the study area can be characterized as a freshwater tidal mudflat.; while, according to the Ramsar classification, the study area is a coastal wetland belonging to the G-category, characterized by intertidal mud, sand or salt flats.

4.3 Geographical Position and Topography of the Study Area

4.3.1 Location of the study area

The study area is an integral part of the Khulna-Jessore Drainage and Rehabilitation Project (KJDRP), which is a fairly large project in the water resources sector in Bangladesh. The KJDRP is spread over six sub-districts[1] (namely, are Dumuria, Phultala, Daulatpur, Batiaghata, Paikgachha, Khulna Sadar) of Khulna district and five sub-district (namely, Keshabpur, Manirumpur, Abhoynagar, Jhikargacha and Jessore Sadar) of Jessore district (ADB, 1993, p. 10). It is to be mentioned here that varying percentage of areas from each of these sub-districts constitute the command area of the project, which is roughly demarcated by the railway line connecting Jessore and Khulna in the north and east, the catchment of the Kobadak River in the west and south, the Lower Sholmary, Salta and Upper Bhadra Rivers (CEGIS, 1998; SMEC, 2002a). However, the study area is spread over two *beels* (natural depressions), namely beel Dakatia and beel Bhaina. Beel Dakatia is situated mostly in the Dumuria sub-district and a minor part of the beel falls in the Phultala sub-district, while beel Bhaina is entirely situated in the Keshabpur sub-district.

4.3.2 Topography and tidal range

The elevation of the northern part of the KJDRP project is relatively high compared to other parts, and drops from an elevation of 14 metres to 6 metres (PWD), with an average slope of 1:7500. This area is no longer under the influence of tides. The central and southern parts are low lying areas containing many natural depressions (locally known as *beel*) and these areas are very susceptible to tidal flooding since they are under the direct influence of the Bay of Bengal. It is worth mentioning that

[1]The next administrative unit under a district is called a sub-district which is presently known as Upazila and previously was known as Thana.

Map 4.1: The KJDRP command area

Source: ADB, Asian Development Bank (2007) the study area falls into the central part of the KJDRP. These two areas (i.e., the central and South-eastern parts of KJDRP) experience the same semi-diurnal tides as in the Bay. However, they experience varying ranges of tides temporarily and spatially; spring tides vary from 2.5 to 3.5 metres and neap tides between 1.5 and 2.5 metres, while the volume of tide dwindles as it further approaches the north (CEGIS, 1998, p. 139; SMEC, 2002b, p. 2-2). Needless to say, tidal ranges vary markedly between monsoon and dry seasons.

4.3.3 Salinity and sediment concentration

In the southern part, the salinity level starts rising in November and continues to rise until it reaches its peak in May. Readings from the two points, Ranai and Dohori, along the Hari River during the year 2001 recorded that surface water salinity was 4 g/l (grams per litre) at both points, which increased to 13 g/l in mid-May and then decreased to 5 g/l by the end of June. Nonetheless, salinity levels in the rivers flowing to the south of the KJDRP (e.g., the Lower Sholmary, the Gagnrail, the Telegati, etc.) vary from 15 to 20 g/l, while the maximum salinity in the Bay of Bengal is recorded as between 25 to 30 g/l (CEGIS, 1998 p. 139; SMEC, 2002b, p. 2-2)

Sedimentation in the project area is considered to be the key factor as it is the root cause of drainage congestion and waterlogging hazards in the area. The primary source of sediment in the area is the Bay of Bengal, from which the sediment is transported upstream with the rising tides. Silt and clay are the main constituents of sediment in the KJDRP area. Sediment concentration in the project area is higher in the dry season and lower in the wet season.

4.4 Hydrology and River Morphology in the Study Area

Most part of the KJDRP project area is crisscrossed by semi-diurnal tidal rivers and creeks, providing a complex drainage network to a system of embanked hydrological setup i.e., polders (ADB, 1993; Tutu et al., 2005). Natural depressions or beels are found to exist in the lower parts of these polders. These polders were designed considering the gravitational drainage system, and these beels are connected to the drainage network through regulators. The main rivers in the KJDRP area include the Bhadra, the Harihar, the Hari, the Mukteswari, the Hamkura, the Sholmari, the Teligati and the Ghangrail. These rivers form four distinct drainage network systems in the KJDRP area (CEGIS, 1998; SMEC, 2002b):

(i) the Upper Bhadra System (with the Harihar and the Upper Bhadra Rivers)
(ii) the Hari River System (with the Mukteswari and theTeka-Hari Rivers)
(iii) the South-eastern System (with the Upper Sholmari and the Hamkura Rivers)
(iv) the Teligati-Ghangrail system (with the Telegati and the Ghangrail Rivers)

4.4.1 The Upper Bhadra System (UBS)

The Upper Bhadra system drains about 33,000 hectares of land comprised mainly of catchments of the Harihar (16,500 ha) and the Upper Bhadra (11,700 ha). The Upper Bhadra River drains its own catchment plus the discharge it receives from the Harihar and the Buribhadra. The UBS has both non-tidal and tidal segments; the upper parts of the Harihar and the Buribhadra Rivers are no longer under tidal influence. Buribhadra is a small tributary of the Upper Bhadra River. The non-tidal parts of this system drain well; however, drainage congestion exists in the southern tidal part due to siltation in the Upper Bhadra River. As a preventive measure against this siltation, a seasonal cross dam is set across to the Upper Bhadra River at Kashimpur to restrain tidal flows during the peak sediment period (CEGIS, 1998, p. 136; SMEC, 2002b, p. 2-4).

4.4.2 The Hari River System (HRS)

The Hari River system is the main drainage catchment of the Mukteswari (approx. 29,200 ha) and the Hari (approx. 16,000 ha) Rivers. The Mukteswari is no longer a tidal river since tides are restricted by the Bhabadah regulator (designed with flap gates). This regulator (Bhabadah) is located at the upstream end of the Hari River. The eastern part of Hari catchment used to drain through the Hamkura River; later, it was diverted to the Hari River when the Hamkura River became virtually inoperative due to severe siltation in the early eighties. It is worth noting that beel Bhaina (belonging to polder-24) is drained by the Mukteswari-Hari river system. The TRM system in beel Bhaina was operated through the Hari River system and the subsequent TRM operations are also operated through the Hari River system (CEGIS, 1998, p.136; SMEC, 2002b, p. 2-3)

4.4.3 The South-eastern System (SES)

The South-eastern system drains three polder areas: polder-25 or beel Dakatia (14,300 ha), polder-27 (4,870 ha) and polder-28 (8,040 ha). Beel Dakatia, i.e., polder-25, entirely drains into the Upper Sholmari River through the Sholmari regulator ever since the dying of the Hamkura River; the upper part of polder-27 also drains through this regulator, while the other parts of this polder drain through the Teabunia regulator, as well as through some pipe outlets. Previously, the western part of beel Dakatia and polder-27 would drain into the Hamkura River until siltation in the River Hamkura reached such a state that the regulators along this river became inoperative. While, polder-28 drains into the Lower Sholmari River through Ramdia-Joykhalikhal via the Ramdia regulator (CEGIS, 1998, p. 138; CEGIS, 2001, p. 7, 20, 30; SMEC 2002b, p. 2-3). It is to be mentioned here that the South-eastern system is regulator-based, and it prevents tidal flows from entering into the polders.

4.4.4 The Teligati-Ghangrail System (TGS)

This system evolved from the confluence of some of the rivers of the above-mentioned drainage systems. The Hari and the Upper Bhadra Rivers converge at Kashimpur and create the River Teligati, which flows up to Shibnagar; there it joins with the main Bhadra River. The combined flow of the Teligati and Bhadra Rivers is known as Ghangrail River and it continues to flow further downstream. However, TGS is still functioning well in terms of draining the upstream catchments, although the system is silting up slowly because of reduced upstream flow (CEGIS, 1998, p. 138).

These river systems drain into the Bay of Bengal through the mighty tidal rivers in the downstream including the Arpangasia, the Shibsa and the Passur. However, the study area in this research relates to the second and third river systems.

4.5 Farming Practices in the Study Area

Paddy and fisheries, the two mainstream crops in the study area, are produced over a one-year period. Transplanted boro is the predominant paddy variety and it is grown in the winter dry season (i.e., during January to April); while three varieties of fisheries are produced over a period of more or less eight months. The fisheries varieties are, freshwater prawn (*Macrobrachium rosenbergii*) locally known as *golda chingri*, brackish water shrimp (*Penaeus monodon*) locally known as *bagda chingri*, and carp fisheries locally known as *shada mas* (white fish). Growing period of these fisheries vary between three to eight months; but in reality, it depends on the will of the farmers. It is noteworthy that each of these three varieties can be grown in the TRM operated area, unlike the SRM operated area. The brackish water shrimp are not cultivated in the SRM operated area, because of unavailability of brackish water. However, farm management, as well as farming practices, for paddy and fisheries are different to some extent from the typical farming practices in Bangladesh, since they are produced on the same farm by rotation and, most importantly, in a special agro-hydrological environment. This type of farming is widely known as '*gher* farming'. Kamp and Brand (1994, cited in Ahmed et al., 2008) branded gher farming as a quiet, indigenous technological revolution suitable for prawn, white fish (carp variety) and rice cultivation. Gher farming in the study area can be termed as a kind of integrated aquaculture-agriculture (IAA) (see Nhan et al., 2007; Ahmed et al., 2010)

The term 'gher' in Bengali generally refers to an enclosed area surrounded by fences/walls. In agriculture, it refers to a farmland surrounded by peripheral earthen dykes giving it a pond like shape, within which both paddy and fisheries are grown through maintaining/manipulating the inner hydrology as required. As part of hydrology control, at least, one canal and a tub are excavated within the gher. The main purpose of the canal is to retain water for the dry season, primarily for the purpose of managed pisciculture, although the retained water can be used for other purposes including irrigation. The tub is used as a nursery for very small fries to let them grow up to a certain size. In practice, fries are allowed to grow up to fingerling or such a size, when it is safe to discharge them into the gher water among other fisheries.

The canal is usually excavated along the inner periphery of the dykes and the tub in a convenient location. The depth of the canal with respect to the adjacent paddy land varies between 3 to 5 feet on average, whilst the tub is shallower than the canal and the depth hardly exceeds 2 feet. The hydrology inside a gher is basically maintained by pumping water in or out. There are instances where the hydrology is maintained naturally, at least partially, and it depends on the area and location of the gher, and above all, whether climatic conditions that it rolls over normally. General expectancy here that the gher receives enough water from rainfall to start with pisciculture by June, while it would get dry enough by January to start with paddy cultivation/transplantation. Paddy is grown in the rest of the gher area, other than the canal and tub. Usually, repairing the dykes and cleaning the spoils from the canals and tub are done before starting of pisciculture; however, the frequency of these works depends on a number of factors, including soil texture, water pressure etc.

4.6 Data Collection: Questionnaire Design and Sampling Methods

4.6.1 Preparation for data collection

The present study estimates agricultural productivity as the core part of the performance evaluation of the two competing FCDM systems analysing data on paddy and fisheries production. The main reason for considering paddy and fisheries is that these are the two dominant crops produced with the FCDM systems over a cropping year. In the existing farming practice, these two crops are mutually overlapping, at least, to some extent. Thus, a joint set of questionnaires was prepared to collect primary data. At the same time, a few informal Focus Group Discussions (FGD)(see Appendix 4) were carried out on predetermined set of questions relating to a number of issues, such as the background of the interventions, pre- and post-intervention productivity levels, the possible scenarios and so on. In these discussions, people from all walks of life including stakeholders, teachers, people's representatives in local government institutions, the former and incumbent chairmen and members of concerned union parishads (the lowest tier of the administrative unit of local government), and local elites were made available. Prior to the FGDs, a good number of informal meetings were arranged with concerned people, comprising stakeholders, agricultural extension officers, NGO officials, experts in water resources management, engineers and economists, to discuss the overall situation under the two interventions. Some of these meetings, discussions and FGDs were held at workplaces of the concerned people, and some were held at local tea-stalls/marketplaces. Local stakeholders habitually pass their leisure time in local tea-stalls/marketplaces; so it was easier to get the stakeholders for a meeting or an FGD. These discussions provided necessary information for developing the framework for the questionnaire design, data collection method and formulating policy recommendations.

4.6.2 Strategies adopted to ensure accuracy of data

At the very beginning of data collection, enumerators were chosen from each selected village so that problems related to gate-keeping could be solved easily. The researcher became a known person in the study area due to his frequent visits. He used to hire a local motor bike driver and his motorbike for visiting different places in the study area and this made easier for the researcher to develop a friendship with the local people. This friendship helped him to find out honest, educated and active young people to form a sincere team of data enumerators. For each village, a team of two persons were chosen, and in total, there were 14 teams comprised of graduate and undergraduate students, who were trained later in two groups. The group for beel Bhaina was comprised of 5 teams, while the remaining 9 teams formed the group for beel Dakatia. Initially, some questionnaires were administered with the direct involvement of the researcher, and some sample copies were supplied to each team during the training session (of the enumerators) in order to share practical experience with the enumerators in advance. Over the period of data collection, the researcher himself, along with a well-trained assistant, frequently visited the area to supervise the data collection activities.

The logic behind forming a team with two persons is twofold: saving time and giving the interviewee no scope to feel bored, as one person posed the questions to the interviewee while the other recorded the interview. The interviewers were also instructed to check and verify each item at the end of each interview session to ensure that everything had been recorded properly. If there were any information overlooked or obscure, the concerned farmers were contacted or revisited to obtain the missing or correct data; this justified preserving the phone numbers of the respondents in the first section of the questionnaire. In this section, the name of the specific plot on which the farmer provided information was also recorded to remind the farmer later (if need be) about which one of his plots data were collected. Meanwhile, to achieve the highest accuracy and lowest distortion, the questionnaire was designed in such a way that there remains no ambiguity and, at the same time, it is neither embarrassing nor time-consuming.

4.6.3 Techniques of sampling and sampling frame

Selection of appropriate sampling techniques is crucial to the sampling procedure for studies in the social sciences. The unbiasedness of the parameters and the degree of precision of the study results mostly depend on the selection of an appropriate sampling technique. The two main sampling techniques are 'probability sampling' and 'non-probability sampling'. The present study, however, adopted probability sampling because it is much better than the non-probability sampling for a number of reasons, including,

i) unlike a non-probability sampling, a probability sampling covers the whole population in the sampling procedure;

ii) in probability sampling techniques, the sample is selected systematically and randomly, which ensures an equal likelihood of each element or unit being drawn in a sample; and

iii) unbiased estimates of the mean, variance and standard error can confidently be derived from a probability sampling, which leads to drawing realistic conclusions from the study.

There are several forms of probability sampling e.g., simple random sampling, stratified random sampling, systematic sampling, cluster sampling, sub-sampling or multistage sampling. Considering the characteristics of the population and the reality of the study area, the present study applies a combination of three types of probability sampling, namely, stratified random sampling, simple random sampling and multistage sampling. In stratified random sampling, the whole population is first divided into sub-populations; these sub-populations are called strata. Stratification is a process by which the entire population is divided into strata or subgroups with a view to making separate selections from each (Warwick and Lininger, 1975, p. 96). Symbolically, if the whole population consists of N units and is divided into n_1, n_2, n_3, . . ., n_m, strata (sub-populations), then $n_1 + n_2 + n_3 + \ldots\ldots + n_m = \sum_1^m n = N$; (where m is any positive number). That is, sub-populations or strata are non-overlapping, and together they comprise the whole population. Once the strata are determined, samples can be drawn from each stratum independently. If samples are randomly drawn from each stratum, the whole procedure is termed a 'stratified random sampling'. This is a powerful technique and is widely used in social science research. According to Cochran (1977, p. 89), stratification is an important technique as it helps to acquire accuracy in the estimates of characteristics of the entire population.

Like most social science research, this study also uses a 'sampling frame' for convenience. A sampling frame (or survey frame) is a source of material or list used to define a researcher's population of interest. In other words, the sampling frame defines a set of elements from which a researcher can select a sample of the target population. Because a researcher rarely has direct access to the entire population of interest, it is essential from a time and resource constraints point of view to rely on a sampling frame. Each of the two beel areas holds a number of villages and the population of this study (e.g., farmers who produce paddy and fisheries) are spread across these villages. To make a sampling frame, farmers from each sampled village are listed with their landholdings at the outset of data collection. 'Starting at one end of the village and finishing at the other end' was the technique applied. In small villages, most of the farm households were considered, but for the big ones every other household were considered. Two sampling frames were made, one for each beel area. From this sampling frame, a proportionate distribution of different household strata was calculated, which was used to determine the ratio of the sample size of each stratum for each beel.

4.7 Procedures Applied to Data Collection

4.7.1 Selection of study area: The Beels with FCDM

Two depressed areas—beel Dakatia and beel Bhaina—where the two FCDM systems were applied, were chosen for this study. The SRM system was implemented in beel Dakatia. In fact, SRM is a stationary system, and there is no scope for shifting the system from one beel to another. In contrast, TRM is basically a rotational system and it had already been applied to several beels (namely, beel Kedaria, beel Bokor, beel Baruli and beel Bhaina); therefore, one might assume that there was scope to choose a beel randomly from many. But in reality, it was not possible since there was no beel other than beel Bhaina, where TRM had completed its full course of action. So, both of the beels were purposively selected for this study.

There are justifications for subdividing each study area further for a representative sample survey. Notably, land elevation across a beel is not the same, since it passes through different hydrological regimes. Considering this reality, each beel is divided into two parts—the upland part and the lowland part—with a view to obtaining representative data for unbiased estimates. Survey evidence shows that the percentages of upland and lowland areas in beel Dakatia are approximately 40% and 60%, while those in beel Bhaina are approximately 35% and 65% respectively.

4.7.2 Selection and distribution of farm households (HHs)

As stated earlier, multistage sampling procedures were followed to select the farm households (HHs) from each of the beel areas. In the sampling procedures, the principles of proportionality were maintained for a representative number of elements in each sample. Several villages were selected by simple random sampling from both of the upland and lowland parts of each beel in proportion to the area of each part. Farm households for each sampled village were then stratified into small, medium and large groups based on land holdings[2], drawing on the classification used by the Bangladesh Bureau of Statistics (BBS) in its 'Agricultural Census for 2007' (BBS, 2009). Again, this study made some modifications in the classification, considering the reality of effective land holding in the two parts of the study area.

Table 4.1: Stratum of the farm households

Size of Stratum	Landholding of the Households
Small	0.05 to 2.49 acre
Medium	2.50 to 7.49 acre
Large	7.50 acre or above

Source: BBS, Bangladesh Bureau of Statistics (2009)

(i) Sample size

In a sample survey, the normal practice is to select such a sample size that represents a true picture of the population. A representative sample size is one which helps to provide unbiased estimates of the population, although the size actually depends on the variability of the elements in the population. In the case of stratified sampling, when the strata differ not only in size but also in variability, it is considered reasonable to take a larger sample from the strata with more variability and a smaller sample from the strata with less variability. However, there is no hard and fast rule as to how large a sample size must be to ensure the normal approximation (Cochran, 1977). A number of studies, including Wadud and White (2000), Rahman and Hasan (2011), and Islam et al., (2004), used sample sizes between 200 and 300 for empirical

[2]In calculating the total landholding, leased-in lands were taken into account. Because farmers cultivate the leased-in lands as his/her own land, this contributes to changes in the farming practices as well as economic status of the farmer.

studies involving stochastic frontier analysis (SFA). The present study, however, uses a fairly large sample size of 357 households for the production year of 2011/2012. From beel Dakatia, a total of 205 households were taken into consideration, of which 123, or 60%, were from lowland areas, and 82 or 40% from upland areas. The sample sizes from upland and lowland areas for beel Bhaina were 99 (or 65%) and 53 (or 35%) respectively, making a total of 152 sample households. Again, stratum-wide distribution of these sample households for each area was maintained, following the proportionate distribution of farm households for each stratum for the respective beel.

Table 4.2: Sampling distribution of rural households in the study area

Rural land holding group	Percentage of HHs in beel Dakatia area	Percentage of HHs in beel Bhaina area
Small-size farm HH	73.65	75.33
Medium-size farm HH	22.12	21.11
Large-size farm HH	4.46	3.74
Total	100	100

Source: Field Study

Table 4.3: Sample size for beel Dakatia by land type and stratum

Strata	**Land type based on land elevation**		**Beel total**
Stratum name	Lowland	Upland	
Small	91	60	151
Medium	27	18	45
Large	5	4	9
Total	123	82	205

Source: Field survey and table 4. 2

Table 4.4: Sample size for beel Bhaina by land type and stratum

Strata	**Land Type based on land elevation**		**Beel Total**
Stratum name	Lowland	Upland	
Small	74	40	114
Medium	21	11	32
Large	4	2	6
Total	99	53	152

Source: Field survey and table 4.2

A stratified proportionate random sampling technique was followed to collect information from the farm households for this work. This sampling technique provides greater advantages over simple random sampling in many ways, including precision in the estimates. Stratified random sampling gives each sample point (household) an equal chance of being selected from the respective stratum, which helps establish important relationships among the strata, as well as the statistics. In contrast, a simple random sampling technique is very much susceptible to generating highly biased estimates, in which the distribution of sample points is extremely skewed. If simple random sampling is applied to a highly skewed distribution of sample points, as in the case of farm household distribution in Bangladesh, there is a high chance of including none or too many large farm households in the sample, resulting in an unrepresentative sample of the population. Nevertheless, simple random sampling after stratification improves the representativeness of the sample drawn from the same population when subdivisions of the population in terms of strata are known. Importantly, sampling error can be reduced by stratification (Warwick and Lininger, 1975, p. 75); meanwhile, control over sampling error in terms of minimising the variability between population estimates and sample statistics depends on both the sample size and the sample design (Casley and Kumar, 1988, p. 83).

4.7.3 Questionnaire preparation

At the outset, farming practices of the study area were understood through informal meetings and discussions with the stakeholders. Then the framework of the questionnaires was outlined after extensive literature review keeping in mind the SFA model as the principal analytical tool. Finally, the questionnaires were formulated after consultations with some experienced and educated farmers. A pilot survey was carried out on a number of farmers taken randomly from the study area as a test case. In the pilot study, it was revealed that the questionnaire was too long and time-consuming, and some questions were redundant or could be merged with other relevant questions. Thus, taking lessons from the pilot survey, the design of the questionnaire was further improved and eventually a comprehensive and integrated questionnaire emerged. There were two separate sets of questionnaires for each part of the study area, especially for the fishery section, since the brackish water shrimp is not cultivated in both beels. Again, each set was divided into three sections. The first section contained questions relating to the identification of the principal decision maker of the farming operation, family labour statistics, land holdings and its patterns etc. The second section covers issues related to paddy cultivation, including the land type, input requirements and costs, output and returns, access to agricultural extension services and so on; and the third section covers similar issues that apply to fish farming. Appendix 3 presents the complete set of the questionnaires.

4.7.4 The household Survey

As mentioned earlier, the sample households were selected through a series of stratified random sampling and simple random sampling techniques, as applicable. A total of 14 villages were chosen from 41 villages situated within or around the two beels, and from these 14 villages a total of 357 samples, comprised of small, medium and large farm households, were selected subsequently, applying stratified and simple random sample techniques. As a matter of fact, around 380 households were surveyed, but some of the surveyed questionnaires had to reject because of incomplete information and/or poor quality of data. The sample survey was undertaken by the researcher as well as the trained enumerators, using structured questionnaires. Before each session of data collection, the respondents were informed of the purpose of the data and their queries regarding this study were also answered with due respect. This was, in fact, a face-to-face interviewing and the respondents enjoyed full freedom to withdraw themselves from the interview at any point.

Picture 4.1: An Informal Focus Group Discussion

Picture 4.2: An instruction session for the enumerators

Picture 4.3: A meeting with the enumerators

4.8 Ethical Considerations for Data Collection

The ethical principles regarding primary data collection are maintained fully giving more emphasis on the two inalienable human rights: free speech and privacy. At the same time, the collection of data for this study is carried out with honesty, sincerity and integrity where the interviewees, as well as the sources of first-hand information, are briefed about the purpose of this study at the very beginning. They are assured of their rights under the data protection laws and a guarantee of their confidentiality and anonymity (where necessary). At the same time, the data providers are also informed that they have the full freedom to skip any question or give a partial answer, and even they can pull out from the interview at any stage.

4.9 Overcoming the Limitations of the Household Survey

There are shortcomings in agricultural data collection, particularly in developing countries, where most farmers are not well-educated and do not maintain record-keeping for farming activities, resource usages, yields and so on. So, researchers have no other option but to rely on memory recall information from the farmers in most cases. However, to overcome this limitation, the present study adopted two specific strategies. First, the survey was conducted just after the paddy harvest period so that the stakeholders/interviewees could recall information easily. Second, priority was given for holding the interview at the interviewee's own house, so that he/she could have the scope to rectify any information with the help of other family members.

4.10 Summary and Conclusions

The study area—beel Dakatia and beel Bhaina—characterized as freshwater tidal mudflats, and they are integral parts of the Khulna-Jessore Drainage and Rehabilitation Project (KJDRP). Beel Dakatia is situated mostly in the Dumuria sub-district (Upazilla) and a minor part of it belongs to the Phultala sub-district of Khulna district, while beel Bhaina entirely falls in the Keshabpur sub-district of the Jessore district. The drainage networks of beel Dakatia and beel Bhaina are linked respectively to the South-eastern System (UES) and the Hari River System (HRS). Paddy, freshwater prawn and carp fisheries are the most common crops produced in both parts of the study area. In beel Bhaina, brackish water shrimp is produced in addition to these common crops, since farmers with this beel have easy access to brackish water.

The present study adopted a probability sampling approach, involving stratified random sampling, simple random sampling and multistage sampling techniques to collect representative sample observations. Data on paddy and fisheries production in the crop year of 2011/2012 were collected from a sample of 357 households. From beel Dakatia, a total of 205 households were taken into consideration, of which 123 (or 60%) from lowland areas, and 82 or (40%) from upland areas. The sample sizes from upland and lowland areas of beel Bhaina were 99 (or 65%) and 53 (or 35%) respectively, comprising a total of 152 samples. This study followed a face-to-face interviewing technique to collect primary data using structured questionnaires.

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CHAPTER FIVE
STOCHASTIC PRODUCTION FRONTIER ANALYSIS OF PADDY

Chapter Structure

Chapter FIVE
Stochastic Production Frontier Analysis of Paddy

Objective and Organization of the Chapter

The main objective of this chapter is to examine productivity performance of two competing flood control and drainage management (FCDM) systems in terms of technical efficiency of paddy production. The first section of this chapter describes the selection of variables used in the stochastic production frontier (SPF) model and the summary statistics of the variables. The second section explains the empirical models along with the estimated parameters, while the third section presents hypothesis tests and decision rules. Presentation and discussions of estimated results are placed in section four which ends up comparing the FCDM systems in a number of ways. Section five outlines the attempt to develop a pooled model; finally, section six presents the summary and conclusions.

5.1 Introduction

Stochastic frontier analysis (SFA) is a well-established approach to evaluating different types of facilities or programmes or managements that influence production activities as well as the level of productivity. SFA usually uses either the level of output or cost of production or profit, as the basis for evaluating these interventions. When the level of output is used as the basis of evaluation, it takes stochastic production frontier (SPF) analysis to estimate technical efficiency; when the cost of production, it takes stochastic cost frontier (SCF) analysis to estimate cost/economic efficiency, and so on. This chapter, however, applies SPF analysis to evaluate productivity performance of the two competing FCMD systems—Silt-dredging and Regulative-drainage Management (SRM) and Tidal

River-basin Management (TRM)—in terms of technical efficiency of paddy production. Actually, technical efficiency of paddy production overwhelmingly dominates the literature of performance evaluation in agriculture (see Wadud and White, 2000; Tadesse and Krishnamoorthy, 1997; Kalirajan, 1984; Kalirajan and Shand, 1986).

5.1.1 Variables in the stochastic production frontier model

Before selecting the variables for the SPF model, extensive consultations with the farmers and stakeholders were made keeping in mind SFA as the principal analytical tool. These efforts helped to choose the most important factors of paddy production in the study area, in particular, and in the coastal area of Bangladesh in general. Seed, land preparation, irrigation, labour, pesticides and chemical fertilizers are the most common factors of paddy production in Bangladesh and (perhaps) elsewhere in the world. Generally, researchers choose most of the variables from the abovementioned factors when analyzing the frontier production function of paddy. For example, Sharif and Darr (1996) used fertilizer, bullock labour (for land preparation) and family and hired labour in the empirical study of patterns and sources of technical inefficiency in traditional and HYV rice cultivation in Bangladesh. Kalirajan and Shand (1986) used four input variables, labour, fertilizer, operational rice area and an ownership dummy in estimating location-specific and farm-specific technical efficiency in Malaysian agriculture. Dawson et al., (1991) also used four input variables like Kalirajan and Shand (1986), but in place of an ownership dummy, the authors considered an irrigation-related dummy in their study of generalized measures of farm-specific technical efficiency in Central Luzon, Philippines.

However, in the above studies, the authors did not include inefficiency effect variables in the model, meaning these studies considered only the error component model. While, Battese and Coelli (1995) developed a model for inefficiency effects in a stochastic production frontier involving the exogenous variables of irrigated land, ratio of operated land to irrigated land, labour (family and hired), bullock labour for ploughing, and time period (in years). Along with these mainstream variables, the authors also considered age, years of schooling and year as inefficiency variables. Kalirajan (1984) designed a stochastic frontier model with the input variables of labour, fertilizer, land preparation and rice area in association with the farm-specific inefficiency variables of age, education, experience, extent of contact, in terms of number of visits, and an ownership dummy. The primary focus of this study was to develop policies relating to irrigated rice farming in the provinces of Laguna in the Philippines. Wadud and White (2000) considered a model of five input variables for determining the technical inefficiency of farms in Bangladesh, involving land, labour, irrigation, fertilizer and pesticides, along with age, land fragmentation, years of schooling, and dummies for irrigation infrastructure and environmental degradation as inefficiency variables. In determining the production efficiency of Jasmine rice, producers in Nothern and Northeastern Thailand, Rahman et al., (2009) used a translog model with land, labour, fertilizer and irrigation as input variables, as well as five inefficiency variables including farm size, education level and three dummies. Meanwhile, Rahman et al., (2012a) and Rahman et al., (2012b) engaged wide-ranging input variables, namely, human labour, seed, manure, ploughing cost, irrigation cost, insecticide cost and land under production as input variables, while as inefficiency variables the authors included age, education, experience, family size and land under household in modelling the technical efficiency of rice farmers in Bangladesh.

Most of the variables which are usually taken into consideration for the stochastic production frontier for paddy have also been found to be relevant to the present study. These are seed, land preparation, fertilizers and irrigation, and all of them are included in the model. In addition, four environmental variables *viz*, dewatering, its dummy and dummies for different soil qualities have been considered in the model. However, it is the management systems which are held responsible for creating such environmental qualities that require incorporation of these variables in order to reflect their influence in the production system.

With regard to the inefficiency variables, the most commonly used farm-specific variables, e.g., age, education and experience of the principal decision maker of the farming operation are included in the model. Productivity in agriculture is very sensitive to decisions taken by the farm operator regarding the quantity of inputs applied to farms and timing of applications. It is likely that the ownership pattern of the farm would influence these decisions as far as the farm operator's insufficient budget is concerned. However, to consider this phenomenon, the ownership status of the farm has been taken into account, incorporating an ownership dummy into the inefficiency model.

5.1.2 Measurement and summary statistics of the variables

Table 5.1 presents a summary of statistics for the variables of the SPF model for paddy production with the SRM system in beel Dakatia and the TRM system in beel Bhaina. Specifications for most of the input variables in this study match with similar studies carried out by different authors, including Wilson et al., (2001). For example, cost of seed is used in order to consider differences in the quality of different types of seeds; the chemical fertilizers are broken down into their constituent parts, such as urea, muriate of potash (MP) and triple super phosphate (TSP) for an elaborate analysis.

However, an overall picture of the average amounts of inputs and outputs with each of the two management systems is depicted in table 5.1 to compare the competing management systems. Independent sample t-test is carried out with the average amounts to justify the comparison statistically. Test results show that in most cases, average requirement of an input significantly differ from one system to another. Meanwhile, bivariate correlations with the variables reveal that there exist no extreme cases of collinearity between the variables. Calculation of bivariate correlation is a useful method for detecting the presence of collinearity among the variables of an econometric model (see Liu, 2010; Rouf, 1999). Appendix tables 6A and 6B show the bivariate correlation between the input variables used in the stochastic production frontier (SPF) model.

Table 5.1 Summary of statistics of the variables in the stochastic production frontier model

(Measurements against per acre of land)

Particulars	System	Input-output statistics				t-ratio
Variables		Mean	Max	Min	Std. dev	
Seed cost (tk)	SRM TRM	732.35 991.25	1286.72 1783.02	272.72 330.58	230.13 266.39	-9.83*** (0.000)
Dewatering (litre)	SRM TRM	33.39 10.31	76 24	5.26 0	16.60 6.03	18.34*** (0.000)
Land preparation (tk)	SRM TRM	1382.36 1088.34	2931.03 1818.18	0 294.12	713.17 329.30	5.202*** (0.000)
Urea (kg)	SRM TRM	71.49 117.86	111.11 177.97	3.03 41.67	22.87 32.96	-14.89*** (0.000)
TSP (kg)	SRM TRM	58.00 53.48	100 98.04	18.38 0	20.06 26.44	1.77 (0.08)
MP (kg)	SRM TRM	31.06 22.99	73.33 62.50	0 0	16.37 16.09	4.64*** (0.000)
Irrigation (litre)	SRM TRM	9.85 38.68	66.67 68.18	0 3.53	10.14 14.88	-20.60*** (0.000)
Labour (man-days)	SRM TRM	32.99 40.71	57.14 68.88	19 20.83	7.19 9.62	-8.319*** (0.000)
Peaty:D1 Clay:D2	SRM	0.341 0.171	1 1	0 0	-- --	--
Sandy-loamy:D1 Clay- loamy:D2	TRM	0.224 0.214	1 1	0 0	-- --	--
Farm-specific variables						
Age	SRM TRM	39.83 37.91	70 70	18 19	11.03 10.82	1.64 (0.10)
Years of schooling	SRM TRM	8.25 8.65	17 15	0 0	3.65 2.97	-1.14 (0.257)
Experience	SRM TRM	11.65 15.30	30 45	3 2	4.94 9.09	-4.48*** (0.000)
Ownership Dummy	SRM	0.639	1	0	--	-
	TRM	0.32	1	0	--	-
Total yield (kg)	SRM TRM	2670.44 2657.78	4148.15 3769.84	1500 1621.62	612.26 552.07	0.20 (0.840)

*Note: *** significant at 1% level (p<.01);*
*** significant at 5% level (p<.05)*
** significant at 10% level (p<.10);*

(Figures in parentheses indicate p-values)

Source: Field survey

5.2 Empirical Stochastic Production Frontier and Inefficiency Models

The econometric model with stochastic frontier analysis is widely used in measuring the performance of productive units because it conforms to the neoclassical theory of production. In agricultural economics, this approach has generally been preferred because of its flexibility and accommodative nature. The present study uses the following stochastic production frontier (SPF) models to predict the technical efficiency of the farms with the two different management systems, drawing on Battese and Coelli (1998 and 1995), Coelli and Battese (1996), and Kumbhakar (1994) models. Equations (5.1) and (5.2) represent the stochastic production frontier and inefficiency models for paddy production with the SRM system and equations (5.3) and (5.4) represent these for paddy production with the TRM system. In addition, a separate pooled model is developed, combining the above two 'individual models'[1] following Battese and Coelli (1988), with some adjustments. Equations 5.8 and 5.9 in section 5.5 of this chapter present the pooled model.

5.2.1 Empirical SPF and Technical Inefficiency Models for Paddy production with SRM System in Beel Dakatia

$$\begin{aligned} ln\, y_i = \beta_0 + \beta_1\, ln\, x_{1i} + \beta_2\, ln\, x_{2i} + \beta_3\, ln\, [\max\, (x_{3i}, 1 - D_{1i})] + \beta_4\, D_{1i}\, (x_{4i}) + \beta_5\, ln\, x_{5i} \\ + \beta_6\, ln\, x_{6i} + \beta_7\, ln\, x_{7i} + \beta_8\, ln\, [\max\, (x_{8i}, 1 - D_{2i})] + \beta_9 D_{2i}\, (x_{9i}) \\ + \beta_{10}\, ln\, x_{10i} + \beta_{11} D_{3i}(x_{11i}) + \beta_{12} D_{4i}\, (x_{12i}) + \xi_i + \tau_i \end{aligned} \quad (5.1)$$

where '*ln*' refers to a natural logarithm and the subscript *i (i- 1, 2, 3, . . . n)* refers to the i-th sample farm. In the following description notations 'kg' and 'tk' respectively mean kilogram and taka (Bangladesh currency).

[1]Equations 5.1 and 5.2 make an 'individual model' for the SRM; so do equations 5.3 and 5.4 for the TRM. The word 'pooled' must be mentioned before the word 'model' to mean a 'pooled model'.

Specifications of exogenous variables for SRM

y_i = output (kg) for the i-th farm

x_1 = cost (tk) for seed

x_2 = quantity (litre) of diesel used for dewatering paddy fields

x_3 = cost (tk) for land preparation

x_4 = a dummy represented by D_1

D_1 = assumes value 'One' if cost for land preparation is positive, and 'Zero', otherwise

x_5 = amount (kg) of urea fertilizer applied to grow paddy

x_6 = amount (kg) of triple super phosphate (TSP) fertilizer applied to grow paddy

x_7 = amount (kg) of muriate of potassium (MP) fertilizer applied to grow paddy

x_8 = quantity (litre) of diesel used for irrigating paddy field

x_9 = a dummy represented by D_2

D_2 = assumes value 'One' if cost for irrigation is positive, and 'Zero', otherwise

x_{10} = amount of labour (number of man-days) applied for paddy cultivation

x_{11} & x_{12} = represent respectively soil dummies for D_1 & D_2

D_3 = assumes value 'One' if soil type is peaty, and 'Zero', otherwise

D_4 = assumes value 'One' if soil type is clay, and 'Zero', otherwise

Model for Technical Inefficiency Effects

$$\tau_i = \delta_0 + \delta_1 z_{1i} + \delta_2 z_{2i} + \delta_3 z_{3i} + \delta_4 D_{5i}\ (z_{4i}) + \omega_i \qquad (5.2)$$

Specifications for technical inefficiency variables

z_1 = age of the primary decision maker among the farming operators

z_2 = years of formal schooling of the primary decision maker among the farming operators

z_3 = years of experience of the primary decision maker in paddy production

z_4 = a dummy represented by D_5

D_5 = assumes value 'One' if primary decision maker is the owner of the entire paddy land and 'Zero', otherwise

5.2.2 Empirical SPF and Technical Inefficiency Models for Paddy Production with the TRM System in Beel Bhaina

$$
\begin{aligned}
ln\, y_i = \beta_0 + \beta_1\, ln\, x_{1i} + \beta_2\, ln\, [\max\, (x_{2i} , 1 - D_{1i})] + \beta_3\, D_{1i}\, (x_{3i}) + \beta_4\, ln\, x_{4i} + \beta_5\, ln\, x_{5i} \\
+ \beta_6\, ln\, x_{6i} + \beta_7\, ln\, [\max\, (x_{7i} , 1 - D_{2i})] + \beta_8 D_{2i}\, (x_{8i}) + \beta_9\, ln\, x_{9i} \\
+ \beta_{10}\, ln\, x_{10i} + \beta_{11} D_{3i}(x_{11i}) + \beta_{12} D_{4i}\, (x_{12i}) + \xi_i + \tau_i
\end{aligned}
\qquad (5.3)
$$

Meaning of the notations '*ln*', 'kg' and 'tk' are the same as in the previous equations.
Note: The exogenous variables for both of models are the same; however, notational order does not match due to adjustment to zero observations.

Specifications of exogenous variables for TRM

y_i = output (kg) for the i-th farm
x_1 = cost (tk) for seed
x_2 = quantity (litre) of diesel used for dewatering paddy field
x_3 = a dummy represented by D_1
D_1 = assumes value 'One' if cost for dewatering is positive, and 'Zero', otherwise
x_4 = cost (tk) for land preparation
x_5 = amount (kg) of urea fertilizer applied to grow paddy
x_6 = amount (kg) of triple super phosphate (TSP) fertilizer applied to grow paddy
x_7 = amount (kg) of muriate of potash (MP) fertilizer applied to grow paddy
x_8 = a dummy represented by D_2
D_2 = assumes value 'One' if MP was applied to grow paddy, and 'Zero', otherwise
x_9 = quantity (litre) of diesel used for irrigating paddy field
x_{10} = amount of labour (number of man-days) applied for paddy cultivation
x_{11}& x_{12} = represent respectively soil dummies for D_1& D_2
D_3 = assumes value 'One' if soil type is sandy loamy, and 'Zero', otherwise
D_4 = assumes value 'One' if soil type is clay loamy, and 'Zero', otherwise

Model for Technical Inefficiency

$$\tau_i = \delta_0 + \delta_1 z_{1i} + \delta_2 z_{2i} + \delta_3 z_{3i} + \delta_4 D_{5i}\ (z_{4i}) + \omega_i \qquad (5.4)$$

Specifications for technical inefficiency variables

z_1 = age of the primary decision maker among the farming operators

z_2 = years of formal schooling of the primary decision maker among the farming operators

z_3 = years of experience of the primary decision maker in paddy production

z_4 = a dummy represented by D_5

D_5 = assumes value 'One' if primary decision maker is the owner of the entire paddy land and 'Zero', otherwise

Originally, there were ten input variables, including the soil dummies, in each individual beel model; later, two additional dummies were incorporated into each beel model to address the zero observations, as suggested by Battese (1997). The author introduced this adjustment rule in his earlier papers e.g., Battese and Coelli (1995), Battese et al., (1996). This adjustment is necessary to acquire unbiased estimates when there are too many zero observations in the sample. While, in the model for inefficiency effects, there are four inefficiency variables, including age, years of schooling, years of experience and a dummy for land ownership.

5.2.3 Linking this estimation to the theoretical framework

Estimation techniques and theoretical basis of the stochastic frontier analysis (SFA) have been explained in chapter 3. Specifically, section 3.2.2 of chapter 3 introduces the specifications of these models, while section 3.4.3 sheds lights on the estimation techniques of parameters and the prediction of technical efficiency, covering both of the distributional specifications proposed by Aigner et al., (1977) and Stevenson (1980). However, this study predicts farm specific technical efficiency, assuming the normal-truncated normal distributional specification suggested by Stevenson (1980). Selection of a distributional specification has been carried out by likelihood ratio (LR) test, in accordance with the procedure described in section 3.9 of chapter 3 (and presented in section 5.3 of this chapter). The mean of the inefficiency component is given by

$$E(\tau_i|\varepsilon_i) = \hat{\tau} = \mu_{*i} + \sigma_* \left[\frac{\varphi(-\mu_{*i}/\sigma_*)}{1-\Phi(-\mu_{*i}/\sigma_*)}\right] \quad (5.5)$$

The technical efficiency of the i-th farm, according to Battese and Coelli's (1988) formulation, is

$$TE_i = E\,\{\exp(-\hat{\tau_i})\,|\varepsilon_i\} \quad (5.6)$$

$$= \left[\frac{1-\Phi\left(-\frac{\mu_{*i}}{\sigma_{*i}}+\sigma_{*i}\right)}{1-\Phi\left(-\frac{\mu_{*i}}{\sigma_{*i}}\right)}\right].\exp\left(-\mu_{*i}+\frac{\sigma_{*i}^2}{2}\right) \quad (5.7)$$

where, $\mu_{*i} = (-\sigma^2_\tau\,\varepsilon + \mu\sigma^2_\xi)/\sigma^2$; $\sigma^2_{*i} = \sigma^2_\tau\,\sigma^2_\xi\,/\sigma^2$; Φ (.) refers to a standard normal cumulative density function, and φ (.) indicates a standard normal density function (for detail, see section 3.4.3 of chapter 3).

As mentioned earlier (see section 3.7.1 of chapter 3), this study justifies the Cobb-Douglas (C-D) functional form for this analysis. The translog functional form was also tested as an alternative to Cobb-Douglas; but it (translog) gives many low t-ratios and extreme values for certain estimates. There are studies including Dawson et al., (1991) and Tadesse and Krishnamoorthy (1997) that experienced similar problems with the estimates of the translog model, which led them to switch over to the Cobb-Douglas functional form. The maximum likelihood estimation of the parameters (including *β's* and variance parameters, i.e., $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma = \sigma_u^2/\sigma^2$), (using the Cobb-Douglas frontier model), are presented in tables 5.2 and 5.3 for the SRM and TRM systems respectively.

Table 5.2: Maximum-Likelihood Estimates of the SPF Model for Paddy Production with SRM in Beel Dakatia

Variables	Notations	Parameters	Coefficients	Std. errors	t-ratios
Constant		β_0	1.839 (1.546)	0.399 (0.415)	4.60***
Seed	x_1	β_1	0.146 (0.136)	0.043 (0.049)	3.40***
Dewatering	x_2	β_2	-0.110 (-0.123)	0.029 (0.030)	-3.84***
Land prep	x_3	β_3	0.009 (0.004)	0.026 (0.027)	0.35
LP Dummy	D_1	β_4	-0.070 (0.013)	0.197 (0.207)	-0.36
Urea	x_5	β_5	-0.044 (-0.030)	0.034 (0.040)	-1.13
TSP	x_6	β_6	0.209 (0.220)	0.042 (0.044)	4.95***
MP	x_7	β_7	0.006 (0.016)	0.019 (0.019)	0.32
Irrigation	x_8	β_8	0.007 (-0.003)	0.018 (0.020)	0.41
Irrig Dummy	D_2	β_9	-0.013 (0.019)	0.052 (0.057)	0.24
Labour	x_{10}	β_{10}	0.139 (0.125)	0.082 (0.084)	1.69*
Soil Dummy	D_3	β_{11}	-0.126 (-0.117)	0.032 (0.033)	-3.95***
Soil Dummy	D_4	β_{12}	-0.069 (-0.048)	0.039 (0.042)	-1.75*
Inefficiency Model					
Constant		δ_0	0.161	0.212	0.76
Age	z_1	δ_1	0.006	0.003	1.85*
Schooling	z_2	δ_2	0.002	0.007	0.25
Experience	z_3	δ_3	-0.017	0.009	-1.79*
Owner Dummy	D_5	δ_4	-0.041	0.051	-0.80
Model Diagnostics					
Sigma-squared	σ^2		0.053	0.016	3.34***
Gamma		γ	0.786	0.161	4.87***
Log-likelihood			50.68		

*Note: *** significant at 1% level (p<0.01)*
*** significant at 5% level (p<0.05)*
** significant at 10% level (p<0.10*

(Figures in parentheses are OLS estimates)

Source: Own estimation

Table 5.3: Maximum-Likelihood Estimates of the SPF Model for Paddy Production with TRM in Beel Bhaina

Variables	Notations	Parameters	Coefficients	Std. errors	t-ratios
Constant		β_0	1.1133 (1.091)	0.5532 (0.510)	2.0480**
Seed	x_1	β_1	0.0061 (0.025)	0.0540 (0.054)	0.1139
Dewatering	x_2	β_2	0.0843 (0.055)	0.0240 (0.028)	3.5173***
Dewat Dummy	D_1	β_3	-0.1512 (-0.101)	0.0742 (0.083)	-2.0374**
Land prep	x_4	β_4	0.0238 (-0.013)	0.0584 (0.043)	0.4075
Urea	x_5	β_5	0.2150 (0.197)	0.0450 (0.053)	4.7771***
TSP	x_6	β_6	-0.0447 (-0.028)	0.0168 (0.013)	-2.6639**
MP	x_7	β_7	0.0026 (0.005)	0.0180 (0.011)	0.1460
MP Dummy	D_2	β_8	0.0187 (0.015)	0.0398 (0.038)	0.4695
Irrigation	x_9	β_9	0.1180 (0.081)	0.0367 (0.037)	3.2154***
Labour	x_{10}	β_{10}	0.2415 (0.262)	0.0558 (0.061)	4.3239***
Soil Dummy	D_3	β_{11}	-0.1562 (-0.136)	0.0468 (0.040)	-3.3405***
Soil Dummy	D_4	β_{12}	0.0468 (0.065)	0.0333 (0.038)	1.4050
Inefficiency model					
Constant		δ_0	0.3719	0.2403	1.5478
Age	z_1	δ_1	-0.0067	0.0050	-1.3491
Schooling	z_2	δ_2	0.0003	0.0101	0.0330
Experience	z_3	δ_3	0.0055	0.0059	0.98752
Owner Dummy	D_5	δ_4	0.1159	0.0692	1.6741*
Model Diagnostics					
Sigma-squared		σ^2	0.0338	0.0121	2.8047***
Gamma		γ	0.9648	0.2644	3.6491***
Log-Likelihood			71.9153		

*Note: *** significant at 1% level (p<0.01)*
*** significant at 5% level (p<0.05)*
** significant at 10% level (p<0.10)*

(Figures in parentheses are OLS estimates)
Source: Own Estimation

5.3 Hypotheses Testing and Decision Rules

5.3.1 Tests of the hypotheses on inefficiency and pooled models for SPF analysis

This section describes the fundamental rules and procedures involved in hypothesis testing with respect to the specifications of inefficiency model and pooled model.

A model for technical inefficiency can only be estimated if the technical inefficiency effects, τ_i, are stochastic and have particular distributional properties (Coelli and Battese 1996). Therefore, it is of interest to test the following null hypotheses. Most of the rules and procedures of generalized likelihood ratio (LR) tests (defined in equations (3.77) to (3.82) of chapter 3) apply here.

The first null hypothesis, (H_0: $\gamma = \delta_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$), specifies that the inefficiency effects are not present in the SPF model. In other words, the traditional average response model (OLS) is adequate for the SPF model of paddy production with the FCDM systems.

The second null hypothesis, (H_0: $\gamma = 0$), says that the inefficiency effects are not stochastic; i.e., if the parameter γ is zero, the variance of the inefficiency effects will also be zero. So, the stochastic frontier reduces to a traditional mean response function. In this test, the explanatory variables for the technical inefficiency model (e.g., age, years of schooling, experience and ownership dummy) need to be included to the production frontier (Battese and Coelli 1995, and Sharma and Leung, 1999).

The third null hypothesis, (H_0: $\delta_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$), indicates that the intercept and all the coefficients of farm-specific variables are zero. That means technical inefficiency effects have a traditional half-normal distribution (with a mean equal to zero), as originally proposed by Aigner et al., (1977). Rejection of this null hypothesis indicates that a standard stochastic error component model is not appropriate for the half-normal distribution of the technical inefficiency effects (Sharma and Leung, 1999).

The fourth null hypothesis, (H_0: $\delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$), states that coefficients of all the explanatory variables in the inefficiency model are zero, which implies that the technical inefficiency model follows the same truncated normal distribution with a mean equal to δ_0, as suggested by Stevenson (1980). It also asserts that the inefficiency effects are not significantly influenced by the variables in the inefficiency model (e.g., age, years of schooling, experience and ownership) (Coelli and Battese, 1996; Sharma and Leung, 1999). Rejection of this null hypothesis indicates that the combined effect of the four variables on the inefficiency effect on production is significant, although the individual effects of one or more of the variables may be statistically insignificant (Battese and Coelli, 1995).

These null hypotheses can be tested using the generalized likelihood-ratio statistic, λ, given by

$\lambda = -2\,[\ln\{L(H_0)\} - \ln\{L(H_1)\}]$ (as defined in equation (3.76) of chapter 3)

where $L(H_0)$ and $L(H_1)$ denote the values of the likelihood function under the null (H_0) and alternative (H_1) hypotheses, respectively. The results of these hypotheses tests are presented in table 5.4. All the null hypotheses except one with the pooled model have been rejected at 5% level of significance (at best).

Now, it can be deduced that, given the data and model specifications, the farm-specific and management variables considered for the technical inefficiency model contributed significantly, both as a group and individually (for some of them), to the explanation of the technical inefficiencies of the farms with the FCDM systems.

Table 5.4: Hypotheses tests and decisions

Null hypothesis	Log-likelihoods	Test statistic	Critical value (5%)	Decision
Beel Dakatia (SRM)				
H_0: $\gamma = \delta_0 = \delta_1 = \delta_2 = \delta_3 = 0$	41.738	17.89	11.911	Rejected
H_0: $\gamma = 0$	47.659	6.05	5.138	Rejected
H_0: $\delta_0 = \delta_1 = \delta_2 = \delta_3 = 0$	44.464	12.44	9.488	Rejected
H_0: $\delta_1 = \delta_2 = \delta_3 = 0$	44.716	11.936	7.815	Rejected
Beel Bhaina (TRM)				
H_0: $\gamma = \delta_0 = \delta_1 = \delta_2 = \delta_3 = 0$	62.695	18.44	11.91	Rejected
H_0: $\gamma = 0$	68.283	7.264	5.138	Rejected
H_0: $\delta_0 = \delta_1 = \delta_2 = \delta_3 = 0$	64.71	14.41	9.488	Rejected
H_0: $\delta_1 = \delta_2 = \delta_3 = 0$	62.694	18.442	7.815	Rejected
Pooled model				
H_0: $\gamma = \delta_0 = \delta_1 = \delta_2 = \delta_3 = 0$	59.868	12.242	10.371	Rejected
H_0: $\gamma = 0$	62.99	5.998	5.138	Rejected
H_0: $\delta_0 = \delta_1 = \delta_2 = \delta_3 = 0$	61.133	9.712	9.488	Rejected
H_0: $\delta_1 = \delta_2 = \delta_3 = 0$	62.981	6.016	7.815	Accepted
Test of Pooling Models				
H_0: Data can be Pooled	65.989	113.22	31.41	Rejected

Note: The critical values regarding the variance parameter γ are taken from Table 1 of Kodde and Palm (1986).

5.4 Presentation and Discussion of the Results

5.4.1 Estimated parameters and fitness of the SPF models

Tables 5.2 and 5.3 present the maximum likelihood estimates of the stochastic production frontier for the SRM system in beel Dakatia and TRM system in beel Bhaina respectively. With each frontier model, there are two dummies for accommodating zero observations. These dummies are incorporated in order to provide unbiased estimates complying with the statistical procedures mentioned in section 3.6 of chapter 3. However, more than half of the parameters are statistically significant in each individual model. Moreover, if only inputs and model diagnostic variables are considered, at least, eight variables out of thirteen from each individual model are statistically significant which indicate that the econometric models are a good fit. Furthermore, both the estimates of σ^2 (sigma-squared) and γ (gamma) are statistically significant at 1% level for both of models. These estimates testify that the stochastic frontier model is adequate for the present analysis.

The signs of the coefficients of all the input variables with both of the systems are as expected; however, the signs of two estimates, one in each system, require additional explanation. This will be discussed in due course. To begin with the most important factor of paddy production, seed, appears with positive estimates as prior expectations. Seed is significant with SRM ($p<0.01$), but not with TRM. Soil salinity may be the reason why it is not significant with TRM i.e., in beel Bhaina. The coefficients of seed with SRM and TRM have been recorded at 0.146 and 0.006 respectively. It is believed that management interventions and their subsequent impact have changed the production environment in such a way that seed could not render its natural power in both of beels equally.

Chemical fertilizers are assumed to have a greater influence in growing paddy in Bangladesh agriculture and it is believed that chemical fertilizers occupy the second position next to seed. Urea and TSP are the main varieties of chemical fertilizers as far as paddy production is concerned. However, they do not have the same sign in each of the management systems, which may have important implications for this study. Urea appears with negative coefficient in beel Dakatia but with positive in beel Bhaina, whilst, the opposite is true for TSP, i.e., beel Dakatia and beel Bhaina record respectively positive and negative estimates for TSP. These estimates are highly significant ($p<0.01$) except urea in beel Dakatia. TSP appears as the most influential factor among the variables in beel Dakatia with the coefficient of 0.209; in contrast, its coefficient in beel Bhaina is -0.045. Meanwhile, the coefficient of urea in beel Bhaina is 0.215 which is the second highest output elasticity; in contrast, the coefficient of urea in beel Dakatia is -0.044. From the above findings, it seems that urea and TSP are used more than the required amount respectively in beel Dakatia and beel Bhaina. A plausible explanation for the negative estimates is the soil content of the beels. The soil of beel Dakatia is mostly peaty and contains elements which are substitutes for urea; this is why relatively less of urea per unit of land is enough for growing paddy in beel Dakatia compared to other areas. Perhaps farmers use more urea than the appropriate amount in their paddy farms. Hence, it can be inferred that lack of awareness or an information gap (that beel Dakatia soil requires far less of urea), may be the reason for this negative estimate. However, this estimate is not significant. On the other hand, the coefficient for TSP is negative for beel Bhaina, the most plausible reason here may be the salinity of the soil. Salinity hampers growth of plants (Roy, 2008), while TSP is applied to expedite the growth of the plants. Hence, it may be deduced that farmers in beel Bhaina use more of TSP to fight against salinity. However, these findings indicate that the two management systems are quite different in terms of soil content as well as their requirement for different fertilizers. Interestingly, urea and TSP appear with almost the same output elasticity respectively for beel Dakatia and beel Bhaina.

Environmental factors are placed next to chemical fertilizers, particularly urea and TSP, in terms of the degree of relative influence on paddy production in the study area. Dewatering, an important environmental factor, is highly significant ($p<0.01$) in both of beels, but with different signs, as expected. In some parts of beel Dakatia, there exists persistent pseudo-waterlogging and farmers need to pump out water before the transplantation of paddy seedlings; pumping continues at certain intervals for a longer period of time, in some instances untill harvest time. Pumping out water from the paddy field (*gher*-land) before transplantation is a common practice in both beels as the farming system requires. Nevertheless, the extent and duration, as well as costs, are the main consideration here. The magnitude and volume of dewatering in two beels differ significantly, indicating a differential impact of the two management systems, which is also evident from the summary statistics given in table 5.1. However, the coefficients of dewatering with SRM and TRM are -0.110 and 0.084 respectively. On the other hand, irrigation, a reverse action to dewatering, is not widely and intensively applied to most parts of beel Dakatia, unlike beel Bhaina. The output elasticity of irrigation in beel Dakatia (0.007) and is not significant; in contrast, it is highly significant ($p<0.01$); it is in beel Bhaina. The coefficient of irrigation in beel Bhaina is 0.118.

Labour is a vital factor in Bangladesh agriculture like many developing countries since the country's agriculture sector is still far away from a considerable level of mechanization. However, the labour requirement per unit of land for two beels is quite different. Table 5.1 shows that in beel Bhaina the average number of man-days for paddy production per acre is 40.71, which is 23.40% higher than that in beel Dakatia. One of the reasons for this higher labour requirement in beel Bhaina is the overgrowth of weeds, which is removed mostly by human labour. The maximum likelihood estimates of the labour for beel Dakatia and beel Bhaina are 0.139 and 0.242, which are close to those of Wadud and White (2000), Sharif and Dar (1996), Dawson et al., (1991) and Kalirajan and Shand (1986). Importantly, labour is significant for both of beels with p-values of less than 0.01 and 0.10 for beel Bhaina and beel Dakatia respectively.

Like other environmental variables, soil quality has emerged as an influential factor of paddy production with both of the management systems. The soil dummies are considered to be a straight reflection of the alteration and/or retention of the soil quality over time due to the impact of management interventions. In beel Dakatia, both the dummies, i.e., D_3 and D_4 (D_3 for peaty soil and D_4 for clay soil) are negative and significant, with p-values of less than 0.01 and 0.10 respectively. In contrast, only one of the two soil dummies is significant in beel Bhaina. The dummy for sandy-loamy soil, D_3, is highly significant ($p<0.01$) with a negative estimate, while the dummy for clay-loamy soil, D_4, is positive but not significant. These results indicate that in both of beels, loamy soil (a mixture of the soils) is more conducive to paddy production.

The coefficient of land preparation with SRM and TRM are 0.009 and 0.024 respectively, reflecting the fact that additional efforts for land preparation would not be useful. However, this is not surprising, particularly for gher farming (fishpond-cum-paddy field), which is used for transplanted paddy cultivation. Under such farming practice, tillage of land within a gher is not an essential part of the cultivation process since the land remains soft and moisturized enough to transplant seedlings. Actually, most farmers till their land nominally with a view to gaining some advantages (e.g., weed control etc.), while a good number of farmers do not till before transplantation. However, land preparation is not significant for any of the beels.

Finally, returns to scale (RTS) of paddy production with the SRM and TRM systems are respectively 0.362 and 0.647, meaning both of systems are operating under decreasing returns to scale. These estimates of scale elasticity indicate that a 1% increase in all inputs would result in a 0.36% increase in paddy production with SRM, while that with TRM is 0.65%. These RTS estimates are based on ML estimates and these are very close to their OLS counterparts, which are 0.345 and 0.584 respectively for SRM and TRM systems. However, regarding RTS estimates, the TRM system is a more promising management system than the SRM as far as paddy production is concerned.

5.4.2 Estimates of the variables in the inefficiency model

The signs and levels of significance of the farm- and management-specific variables are not the same with the management systems, implying that the production environments are quite different in each of the beels. In beel Dakatia, the coefficient of age is positive, meaning younger farmers are more efficient than the old. This finding is similar to the estimates obtained by Battese and Coelli (1995), Ajibefun et al., (1996), Seyoum et al., (1998) and Wadud and White (2000). The reverse is true for beel Bhaina; however, the coefficient in beel Bhaina is not significant. On the other hand, the coefficients of years of schooling are with positive signs with both of the beels, which conform with the observations of Kalirajan (1984), Wadud and White (2000), Coelli and Battese (1996). Perhaps the availability of information about farming practices (e.g., TV, internet etc.) and easy communication facilities (e.g., mobile phones, facebook etc.) the farmers, particularly by dint of mobile phone, has significantly reduced the gap between farmers with higher and lower levels of educational attainments.

The other two variables, experience and the dummy for ownership status have negative estimates with beel Dakatia, and only experience is significant ($p<0.10$). That means these variables contribute to reducing inefficiency in paddy production with the SRM system.

These findings are in line with the findings of Sharif and Dar's (1996) and Rahman (2003) regarding high yielding variety (HYV) rice cultivation in Bangladesh. In contrast, these two factors have a positive sign with beel Bhaina. Wilson et al., (1998) had similar results regarding years of experience and the author concluded that less experienced producers are more aware of the existing technology and manage their resources accordingly. The same explanation seems applies here also.

Turning to the variance parameter, the estimated value of variance parameter γ is high with both of management systems, suggesting that technical inefficiency effects are dominant compared to statistical noise in explaining the output level of paddy with both of the management systems.

5.4.3 Discussion of technical efficiency scores

The predicted technical efficiency scores for beel Dakatia range from 0.4833 to 0.9593, with a standard deviation of 0.1057, while these scores for beel Bhaina vary from 0.4784 to 0.9801, having a standard deviation of 0.1167. The mean scores for beel Dakatia and beel Bhaina are 0.7808 and 0.7685 respectively. These mean scores are very close to those of Kumbhakar (1994) and Sharif and Dar (1996). However, in the present study, the mean scores indicate that, on average, farms belonging to SRM in beel Dakatia are closer to their respective frontier farms compared to the farms belonging to TRM in beel Bhaina. Again, the standard deviations of scores for these management systems substantiate the above claim.

5.4.4 Distributional patterns of technical efficiency scores using coefficients of skewness and kurtosis

The concepts of skewness and kurtosis are often used to differentiate types of scores belonging to different groups. In order to check the distributional patterns of technical efficiency scores, the coefficients of skewness and kurtosis are computed. Table 5.5 shows the coefficients of skewness and kurtosis for efficiency scores for both of the management systems.

Table 5.5: Coefficients of skewness and kurtosis for technical efficiency ratings by management system

Particulars	Skewness			Kurtosis		
	Coefficient of Skewness	Std. error	Z-value	Coefficient of Kurtosis	Std. error	Z-value
SRM	-0.508	0.170	-2.988**	-0.418	0.338	1.237
TRM	-0.193	0.197	3.817***	-0.681	0.391	1.056

** Significant at 5% level

Source: Own calculation

The coefficients of skewness for technical efficiency scores are negative for both of the management systems, implying that efficiency ratings are skewed to the left. More precisely, skewness coefficients are -0.508 and -0.193 for the SRM and TRM systems respectively, indicating their distributions are moderately skewed and approximately symmetric, in order. These coefficients are statistically significant at 5% level (at best). Since the efficiency ratings of the farms with SRM system are more skewed to the left than its counterpart, a proportionately higher number of farms is concentrated on the right of the mean efficiency score. Moreover, the mean efficiency score of the farms with SRM is higher than that of the farms with TRM. Meaning, paddy production with the SRM system is more efficient than that with TRM.

On the other hand, there is no discernible difference between the coefficients of the technical efficiency ratings of the farms with the two competing management systems in terms of the peakedness (kurtosis) of their distribution. Table 5.5 reports the coefficients of kurtosis for the efficiency scores of the farms for paddy production with SRM and TRM, which are -0418 and -0.681 respectively. The efficiency scores follow platykurtic distribution for both of the management systems, as shown by the shapes of the figures 5.1 and 5.2.

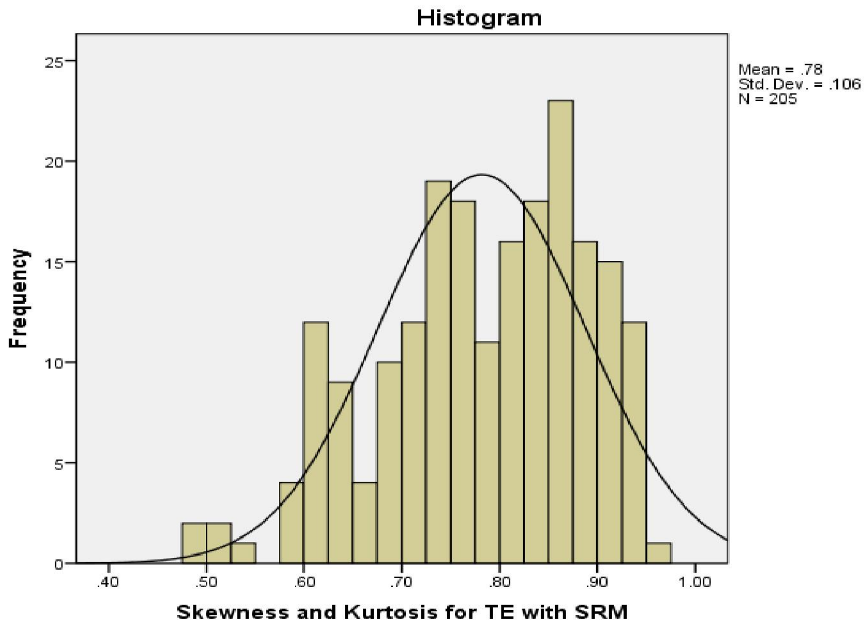

Figure 5.1: Histogram showing skewness and kurtosis for technical efficiency scores with SRM

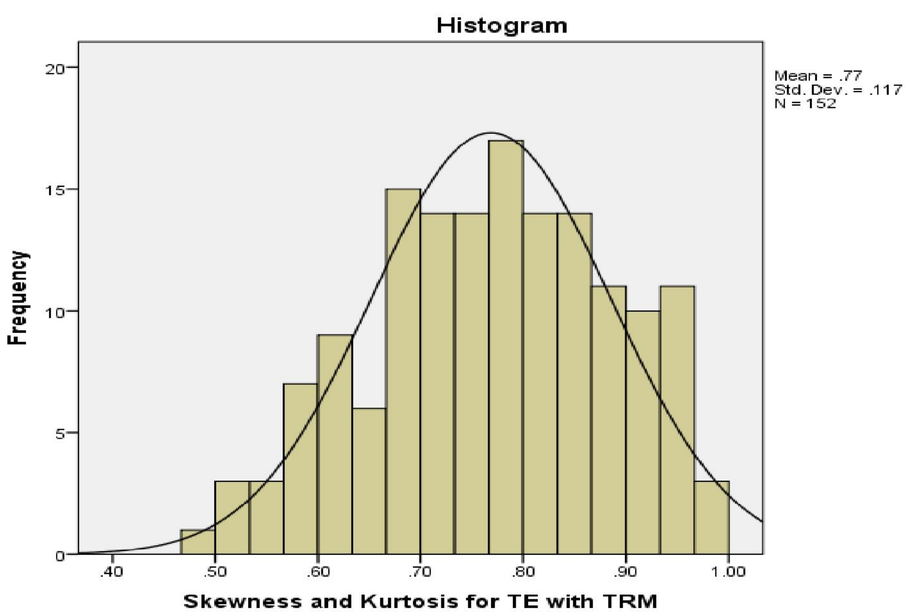

Figure 5.2: Histogram showing skewness and kurtosis for technical efficiency scores with TRM

These results show that the mean technical efficiency scores and the distributional patterns of the technical efficiency scores for the competing management systems are very close to each other. Therefore, it can be inferred from the above results that the SRM system performs better than TRM regarding paddy production by a narrow margin.

5.4.5 Independent sample t-test and Levene's test for equality of variance for mean technical efficiency scores

In addition to distributional patterns of technical efficiency ratings, independent sample t-test and Levenes' test for equality of variance, F-test, were performed for the efficiency scores to check whether the difference between the management systems is statistically significant. Table 5.6 shows these tests results by management system.

Table 5.6: Independent sample t-test and F-test for mean technical efficiency

Particulars	Technical efficiency statistics				Hypothesis tests	
Systems	Mean tech efficiency	Std. deviation	Maximum	Minimum	Levene's test for equality of variance	t-test for equality of means
SRM	0.782	0.106	0.959	0.483	1.911 (0.168)	1.124 (0.262)
TRM	0.769	0.117	0.980	0.478		

Source: Own estimation

To test the hypothesis, if the mean technical efficiency score of the farms belonging to SRM and TRM systems are the same, an independent sample t-test was carried out. Besides, the assumption of homogeneity of variances was also tested by F-test. The independent sample t-test is associated with a statistically insignificant effect, with t-(355) = 1.124 and p = 0.262, indicating that the mean technical efficiency score of the farms belonging to SRM and TRM are not statistically different. Meanwhile, the test of homogeneity of variance (i.e., F-test) provides, F =1.911 and p= 0.168 (degrees of freedom 355), i.e., the null hypothesis cannot be rejected, meaning the equal variance holds true in this case. The above findings indicate that the two management systems are similar in terms of mean technical efficiency of paddy production.

5.4.6 Presenting the efficiency scores by frequency distribution and percentage share

Farms are grouped in terms of the range of technical efficiency score they fall into. There are two types of grouping, one is based on 5-point score interval and the other is 10-point score interval (expressed as 5% and 10% class interval, since the total point is 100). Further, frequency distribution and percentage share of the farms are made from the above groupings in order to compare the management systems in detail. Table 5.7 presents the frequency distribution and percentage share of the farms against various efficiency ranges.

Table 5.7: Frequency distribution and percentage share of TE scores by 5% and 10% class interval

Technical efficiency	Frequency (number of farms belonging to)				Percentage share of farms with			
Particulars →	SRM (beel Dakatia)		TRM (beel Bhaina)		SRM system		TRM system	
	Class interval		Class interval		Class interval		Class interval	
Ranges ↓	5%	10%	5%	10%	5%	10%	5%	10%
Below 0.50	2	2	1	1	0.98	0.98	.66	0.66
0.50 - >0.55	3	7	4	13	1.46	3.41	2.63	8.55
0.55 - >0.60	4		9		1.95		5.92	
0.60 - >0.65	21	35	12	30	10.24	17.07	7.89	19.73
0.65 - >0.70	14		18		6.83		11.84	
0.70 - >0.75	31	60	24	45	15.12	29.27	15.79	29.61
0.75 - >0.80	29		21		14.15		13.82	
0.80 - >0.85	34	73	25	39	16.59	35.61	16.45	25.66
0.85 - >0.90	39		14		19.02		9.21	
0.90 - >0.95	27	28	16	24	13.17	13.66	10.53	15.79
0.95 and over	1		8		0.49		5.26	
Total	205		152		100.00	100.00	100.00	100.00

Source: Own estimation

It is evident from table 5.7 and graphs 5.3 and 5.4 that a higher percentage of farms belonging to the SRM system fall into the upper range of efficiency scores. For example, 49.27% percent farms with the SRM attain an efficiency score of 0.80 or above, whereas only 41.45% of farms with the TRM achieve this score range. A contrary picture is seen for the score range of below 0.60, where the percentage of farms belonging to TRM is higher (9.21%) than that with SRM (4.39%). While in the case of the middle range percentage of farms belonging to TRM marginally exceeds that of its counterpart by 3%. These findings indicate that the SRM system performed relatively better than the TRM for paddy production.

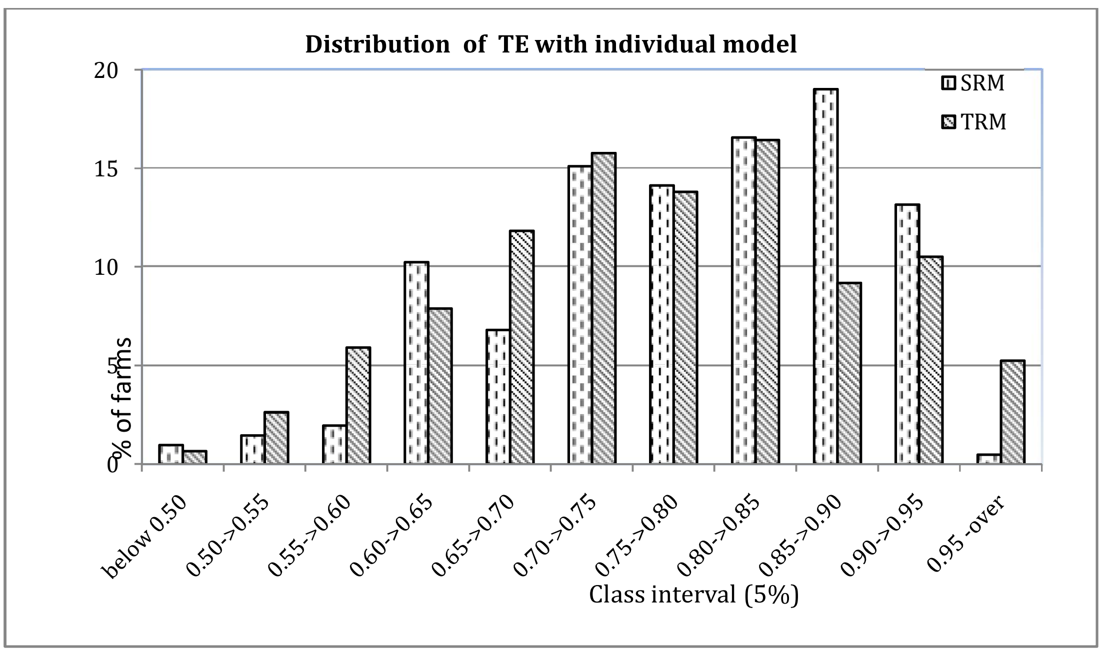

Figure 5.3: Histogram presenting percentages of farms based on score range of TE by management system

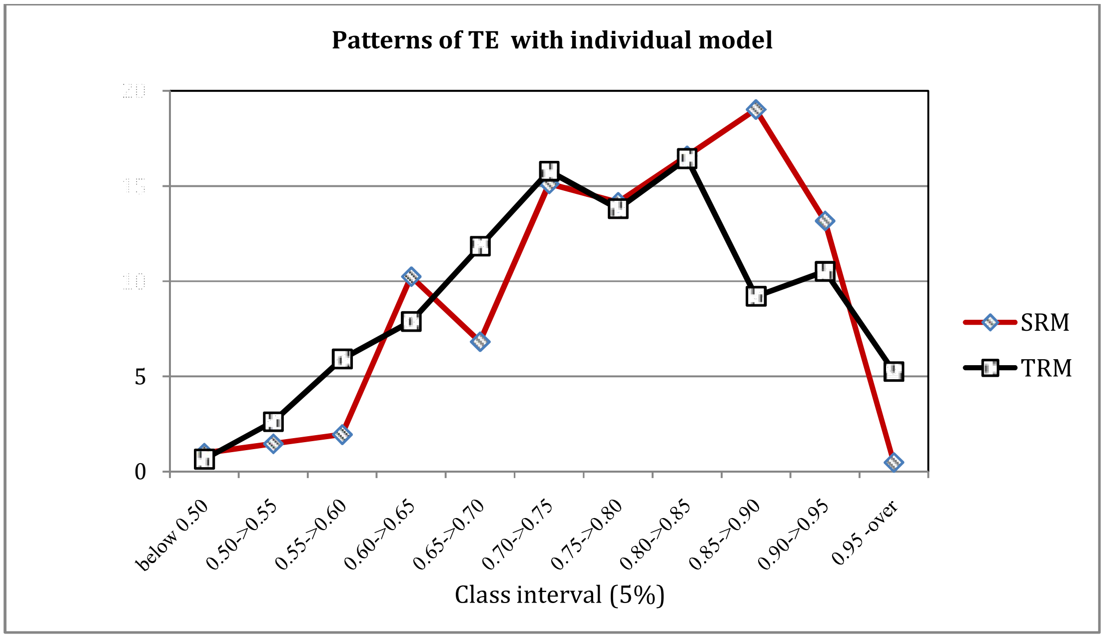

Figure 5.4: Patterns for technical efficiency scores by management system

5.5 Pooled Model for Estimating Technical Efficiency

5.5.1 Developing a pooled model for paddy production

This study makes an attempt to develop a pooled model, combining the above individual (sub-sample) models relating to each of the FCDM systems with some necessary adjustments to the explanatory and dummy variables. Regarding the explanatory variables, the adjustment is nothing but a combination of the three chemical fertilizers—urea, TSP and muriate of potash—to form a single variable NPK (i.e., nitrogen, phosphorous and potassium). This is, in fact, an essential adjustment to avoid too many zero observations in the pooled model. There are empirical studies (e.g., Kalirajan, 1984; Wadud and White, 2000; Coelli et al., 2002; Rahman et al., 2012b; Rahman and Rahman, 2008; Sharif and Dar, 1996) that used NPK as a single variable. Meanwhile, soil dummies of individual (sub-sample) beel models have been replaced by a new dummy variable for each beel. It is expected that this new dummy would surrogate the soil dummies of the individual models as well as the environmental factors of the beels. Kumbhakar (1994) used regional dummies to capture the differential effects of soil, terrain and weather in a study of efficiency estimation of paddy production involving three regions of the Indian state of West Bengal. The regional dummies in Kumbhakar (1994) and the beel dummies in the present study serve almost the same purpose. It is expected that this adjustment helps avoid possible multicollinearity problems among the dummies. Furthermore, this modification helps evade model specification errors, in particular, overfitting the model (see Gujarati and Sangeeta, 2007, p. 521). On the other hand, three inefficiency variables are considered in the pooled model, dropping the *age* variable for the sake of maintaining a balance among the variables. On the whole, all these adjustments contribute to having a pooled model with more statistically significant parameters. Equations (5.8) and (5.9) of the present chapter represent the pooled model for paddy production with SRM and TRM management interventions.

5.5.2 Empirical Stochastic Production Frontier and Technical Inefficiency Models for Adjusted Pooled Data

$$\begin{aligned} ln\, y_i = \beta_0 + \beta_1\, ln\, x_{1i} + \; & \beta_2\, ln\ [\max\ (x_{2i}, 1 - D_{1i})] + \beta_3 D_{1i}(x_{3i}) \\ & + \beta_4\, ln\ [\max\ (x_{4i}, 1 - D_{2i})] + \beta_5\, D_{2i}\,(x_{5i}) + \beta_6\, ln\, x_{6i} \\ & + \beta_7\, ln\ [\max\ (x_{7i}, 1 - D_{3i})] + \beta_8 D_{3i}\,(x_{8i}) + \beta_9\, ln\, x_{9i} + \beta_{10}\, D_{4i}\ (x_{10i}) \\ & + \xi_i + \tau_i \end{aligned} \qquad (5.8)$$

where '*ln*' refers to a natural logarithm, and the subscript *i (i- 1, 2, 3, . . . n)* refers to the i-th sample farm. As mentioned above, the notations 'kg' and 'tk' respectively mean kilogram and taka (Bangladeshi currency).

Specifications of exogenous variables for the pooled model

y_i = output (kg) for the i-th farm

x_1 = cost (tk) for seed

x_2 = quantity (litre) of diesel used for dewatering paddy field

x_3 = is a dummy represented by D_1

D_1 = assumes value 'One' if cost for dewatering is positive, and 'Zero', otherwise

x_4 = cost (tk) for land preparation

x_5 = a dummy represented by D_2

D_2 = assumes value 'One' if cost for land preparation is positive, and 'Zero', otherwise

x_6 = amount (kg) of chemical fertilizers applied to grow paddy

x_7 = quantity (litre) of diesel used for irrigating paddy field

x_8 = a dummy represented by D_3

D_3 = assumes value 'One' if cost for irrigation is positive, and 'Zero', otherwise

x_9 = amount of labour (number of man-days) applied for paddy cultivation

x_{10} = a dummy variable for beel represented by D_4

D_4 = assumes value 'One' if the beel is Dakatia, and 'Zero', otherwise.

Model for Technical Inefficiency

$$\tau_i = \delta_0 + \delta_1 z_{1i} + \delta_2 z_{2i} + \delta_3 D_{5i}\,(z_{3i}) + \omega_i \qquad (5.9)$$

Specifications for technical inefficiency variables

z_1 = years of formal schooling of the primary decision maker among the farming operators

z_2 = years of experience of the primary decision maker in paddy production

z_3 = a dummy represented by D_5

D_5 = assumes value 'One' if primary decision maker is the owner of the entire Paddy land and 'Zero', otherwise

However, hypothesis test rejects pooling the sub-sample data and is not persuaded further.

5.6 Summary and Conclusions

Technical efficiency scores of the farms with a management system have been considered here as the principal indicator of its (management system) performance. The technical efficiency scores of the farms with the SRM system range from 0.4833 to 0.9593, with a mean score of 0.782, while the score range for the farms with the TRM is 0.4784 to 0.980, with a mean score of 0.769. Independent sample t-test shows that the mean scores of the two competing management systems are not statistically different from each other; while Levene's test for equality of variances (i.e., F-test) reveals that standard deviations of these scores are also very close to each other. These results express that both of management systems are similar in terms of their productive efficiency of paddy production.

Distributional patterns of the scores are also similar. This was revealed by the coefficients of skewness and kurtosis. The coefficients of skewness for the technical efficiency scores for SRM and TRM are, respectively, -0.508 and -0.193, indicating both of distributions are left skewed, while the coefficients of kurtosis (-0.418 for SRM and -0.681 for TRM) indicate that both of distributions are mesokurtic.

On the other hand, frequency distribution and percentage share of technical efficiency scores for the farm with SRM and TRM show that SRM is better than TRM, to some extent. , in terms of technical efficiency estimates. For example, about 41% of farms with the TRM system have an efficiency score of 0.80 and above, whereas more than 49% of farms from the SRM system fall into this category. The SRM system has surpassed the TRM system for the lower range of efficiency ratings (i.e., below 0.60); hence, the percentage of farms with SRM is lower compared to that with TRM. In the case of the middle range of efficiency scores, the percentage of farms with TRM marginally exceeds its counterpart.

Lastly, returns to scale (RTS) for the SRM and TRM systems are respectively 0.362 and 0.647, meaning a 1% increase in all inputs would result in a 0.36% increase in paddy production with SRM, while with TRM it would be 0.65%. Hence, the TRM system is more promising than the SRM.

The above findings, statistical tests, distributional patterns and shapes of efficiency scores of the farms with SRM and TRM provide the idea that these systems are not remarkably different in terms of productive efficiency of paddy production. However, since two crops are produced annually with these management systems, the final conclusion is to be made after evaluating the performance of the second crop. The next chapter deals with the second crop, fisheries, to provide further information in this regard.

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CHAPTER SIX
STOCHASTIC COST FRONTIER ANALYSIS OF FISHERIES PRODUCTION

Chapter Structure

Chapter SIX
Stochastic Cost Frontier Analysis of Fisheries Production

Objective and Organisation of the Chapter

The previous chapter (i.e., chapter 5) has investigates performance evaluation of the FCDM systems, the SRM and the TRM, in terms technical efficiency of paddy production involving stochastic production frontier (SPF) analysis. The present chapter continues to do the same in terms of cost efficiency of fisheries production involving a contrasting technique, the stochastic cost frontier (SCF) analysis. The first section of this chapter begins with the importance of SCF analysis in the literature of performance evaluation, which is followed by the selection of variables used in the model, development of the formulae for calculating some of the variables and presentation of the summary statistics. The second and the third sections explain empirical models and hypotheses testing respectively, whilst findings are discussed in section four. Section five describes the attempt to develop a pooled model and finally, section six reports the summary and conclusions.

6.1 Introduction

This chapter, as complementary to chapter 5, completes the performance evaluation of the FCDM systems from the standpoint of productive efficiency in agriculture. Since there are predominantly two crops produced in a year with the two management systems, both of the crops need to be involved in the performance evaluation process. Chapter five deals with the first crop, paddy, to estimate technical efficiency and the present chapter takes the second crop, fisheries, to estimate cost efficiency. The farming practices, as well as behavioural assumptions of fisheries production in the study area, are not consistent with Zellner et al., (1966) argument of expected profit maximisation, rather they uphold the framework of cost minimization (see section 3.5.2 of chapter 3 for detail). The behavioural propositions and farming practices are such that cost efficiency justifies for fisheries production in the study area (see Kumbhakar and Lovell, 2000, p. 132). However, considering the reality, the present study applies stochastic cost frontiers to estimate cost efficiency of fisheries production following the principles maintained by Heshmati and Kumbhakar (1997).

6.1.1 Variables in the Stochastic Cost Frontier (SCF) Model

Like the stochastic production frontier (SPF) model in chapter 5, variables in the stochastic cost frontier (SCF) model have been chosen after extensive consultations with the farmers and stakeholders engaged in pisciculture. It is expected that the input variables selected for the stochastic cost frontier model represent the factors of fisheries production in the study area. However, the exogenous variables in the SCF model are fingerlings, feedings, *gher* (pond) preparation, disease control and total output, while the variables in the inefficiency model include 'age' and 'years of schooling' of the principal decision maker of the farming operation, 'ownership status' of the farm and 'extension contact or training' received on pisciculture by the principal decision maker of the farming operation. These variables which are most commonly used in empirical studies of pisciculture with SCF. For example, seed (fry and fingerlings), fish feed, and labour requirements had been used in a number of empirical studies(see Singh 2005; Alam et al., 2005; Inuma et al., 1999; Sharma and Leung, 2000b; Singh et al., 2009; Karagiannis et al., 2002). These three most commonly used inputs can be used in different forms and measurements depending on the circumstances. Another variable which is often taken into consideration is disease control measure; lime and medicines are considered as the major component of this variable. Use of this variable varies with the species of fisheries as well as farming practices.

On the other hand, the inefficiency variables to be used in an empirical study depend on the production environment under consideration. Nonetheless, the most commonly used inefficiency variables include the age, education and experience of the farmer, ownership status of the farm land and extension contact or training. Alam et al., (2005) and Sharma and Leung (1999) included, at least, two of these common inefficiency variables, along with other relevant inefficiency variables. However, in the SCF model of this study, all the common variables are taken into consideration except the experience of the farmer. The reason for excluding 'experience' is the inclusion of other two variables, age and training & extension contact or training, as it is believed that these two variables together would cover the influence of the variable experience in the production process.

6.1.2 Developing formulae for the variables used in the SCF model

When the number of variables relating to a model is high, it is recommended to reduce the number. Here indexing or other methods are usually employed and this practice restricts the parameters, which helps better understand the impact analysis. For example, in a comparative efficiency study of airlines, Kumbhakar (1991) aggregated fifteen categories of labour into a single index, and four categories of output into a single measure. The author used a multilateral index procedure, in line with Caves et al., (1980 and 1982). Meanwhile, Maietta (2000) aggregated three outputs into one index of output, using a Paasche index in the study of the cost inefficiency of Italian Dairy farms. In the case of a multi-output production structure of fish polyculture, Sharma and Leung (2000a) suggest, "a more appropriate measure [of output index] would be a geometric mean or quantity index of the multiple outputs based revenue shares and prices for different fish species". Iinuma et al. (1999) and Sharma (1999) found this indexing method appropriate for their studies.

Sharma and Leung (1999) argue with the appropriateness of using revenue share when a part of the output is consumed by the producers. In such cases, total revenue is no longer a representative of the total output. However, this problem can be solved easily by adjusting the consumed amount with the sold-out output. The consumed amount is adjusted with sold-out output to calculate the total output index in this analysis. Again, the weighted average of multiple outputs is used here to get a single quantity output index with reference to revenue shares.

In this indexing method, a reference product is first selected to convert other outputs into a single unit. The generalized formula for measuring the weighted average of the multi-product production system is given by

$$W_{ji} = \sum_{j=1}^{\theta-1} \left(\frac{P_{ji}}{P_{\theta i}}\right). Q_{ji} \; + \; Q_{\theta i} \qquad (6.1)$$

Where, W_{ji}= weighted average of the multiple outputs of the i-th farm *(i= 1, 2, 3,. . . N)*
P_{ji}= price offered to the i-th farm for the *j-th* output of (*j= 1, 2, 3, . . . θ*)
(θ-th output has been selected as the reference output).
$P_{\theta i}$= price offered to the *θ-th* output of the i-th farm
$Q_{\theta i}$ = quantity of the reference output produced by the i-th farm, and
Q_{ji} = quantity of the *j-th* output produced by the i-th farm.

Since area the farms varies, the weighted average of output quantities are standardized to ward off the effects of farm size (Iinuma et al., 1999). The present study standardizes the weighted average dividing it by respective farm size. Thus,

$$y_i = W_{ji}/F_i \qquad (6.2)$$

where y_i is the standardized output of i-th farm, and F_i is the size of the i-th farm in acres.

Similarly, multiple inputs of the same variety require standardization in order to have a representative single variable. Again, following the suggestions from Sharma and Leung (1999), the study uses the geometric mean of the prices of different species of fish seeds as the fingerling price. The generalized formula for calculating the fingerling price is given by

$$X_i^G = \left[\prod_{k=1}^{S} \frac{C_{ki}}{M_{ki}}.1000\right]^{1/s} \qquad (6.3)$$

Where $X^G{}_i$ = geometric mean of the prices of fish seeds belonging to different species
C_{ki} = cost of seed for the *k-th* species incurred by the i-th farm (*k = 1, 2, 3, . . . S*)
M_{ki} = number of seed of the *k-th* species released into the fish pond (*gher*) by the i-th farm.
It is noteworthy here that the fingerling price is calculated per thousand counts in general.

In the study area, the most common types of fish feeds include fishmeal, boiled rice, bran, dal, oil cake, mollusc and various combinations of these items. However, a few farmers use all these feeds in balanced proportions. Farmers often omit some items and the omitted items are substituted by other feed items, which are relatively cheaper and more easily available to them. Hence, the weighted average of the prices of feeds is an appropriate measure. Unfortunately, information on each feed quantity is not available because farmers often use a composite of several feed items. In these circumstances, a simple arithmetic mean (where the aggregated cost is divided by aggregated quantity of feeds) is a more appropriate way of getting the feed price. While, prices/costs of the rest of the variables are calculated directly from the survey data with little mathematics.

The following table presents a comparison of summary statistics for the variables in the SCF for fisheries production with SRM and TRM management systems.

Table 6.1: Summary statistics of the variables in stochastic cost frontier model

(Measurements are against per acre of gher)

Variables	System	Mean	Max	Min	Std. Dev	F-ratio	t-ratio
Fingerling price (tk)	SRM TRM	2935.69 1454.79	6928.20 3949.68	1400 681.70	727.90 469.12	21.46*** (0.000)	23.32*** (0.000)
Gher preparation cost (tk)	SRM TRM	8126.27 4413.52	28947.37 11250.00	373.98 526.32	5437.35 2626.77	44.53*** (0.000)	8.53*** (0.000)
Feed price (tk)	SRM TRM	25.83 27.49	78.62 45.00	14.29 11.71	6.73 6.38	1.35 (0.247)	-2.36** (0.019)
Disease control cost (tk)	SRM TRM	993.12 455.57	7733.33 2155.17	0 0	1096.94 439.86	42.44*** (0.000)	6.36*** (0.000)
Disease contl. Dummy	SRM TRM	0.9317 0.8224	1 1	0 0	-- --	-- --	-- --
Total output (kg)	SRM TRM	166.65 178.22	602.18 403.51	14.89 19.82	108.85 75.69	13.79*** (0.000)	-1.18 (0.237)
Farm-specific variables							
Age (years)	SRM TRM	39.83 37.91	70 70	18 19	11.03 10.82	0.85 (0.356)	1.64 (0.102)
Years of schooling	SRM TRM	8.25 8.65	17 15	0 0	3.65 2.97	6.87*** (0.009)	-1.101 (0.272)
Ownership Dummy	SRM	0.64	1	0	--	-- --	--
	TRM	0.32	1	0	--	-- --	--
Extension Dummy	SRM	0.2	1	0	--	--	--
	TRM	0.53	1	0	--	--	--
Total Cost (tk)	SRM TRM	59373.34 51388.60	215333.33 135789.47	3557.1 9808.5	36397.24 21662.55	20.25*** (0.000)	2.58** (0.010)

*Note: *** significant at 1% level (p<.01)*
*** significant at 5% level (p<.05)*
** significant at 10% level (p<.10)*

(Figures in the parentheses indicate p-values)

Source: Field survey

Table 6.1 reports an overall figure of the price/cost of the inputs and outputs that relate to in the stochastic cost frontier models against each of the FCDM systems. Independent sample t-test and Levenes' test of equal variance (i.e., F-test) are carried out for each of the variables. It is evident from summary statistics that the corresponding variables belonging to each system are significantly different. While the bivariate correlation of these variables are estimated to test whether the collinearity problem exists or not. Appendix tables 7A and 7B show that the variables in the models are not affected by collinearity problem.

6.2 Empirical Stochastic Cost Frontier and Inefficiency Models for Fisheries Production

The empirical studies dealing with performance evaluation in terms of productive efficiency mostly involve technical efficiency. However, the crucial role of cost efficiency is widely recognised by researchers and policy makers. There are a considerable number of studies that have gone beyond the measurement of technical efficiency and used cost/economic efficiency to investigate the comparative performance of alternative as well as competing production environments/management systems (see Hesmati and Kumbkakar, 1997; Bhattacharyya and Kumbhakar, 1995; Singh 2008; Hiebert, 2002; Rahman, 2002). These studies either estimate cost efficiency, or both cost and technical efficiencies in pursuit of performance evaluation.

However, drawing on the models proposed by Battese and Coelli (1995), Coelli and Battese (1996), and Kumbhakar (1994), the present study develops a stochastic cost frontier (SCF) model for performance evaluation of the two competing management systems. Equations (6.4) and (6.5) represent the SCF model for both of the management systems. A pooled model is also attempted to develop, combining the individual models for SRM and TRM, in line with Battese and Coelli (1988) with some adjustments, and the pooled model is represented by equations (6.6) and (6.6) in section 6.5.

6.2.1 Empirical SCF and cost inefficiency models for fisheries with SRM and TRM systems

$$ln\, c_i = \alpha_0 + \alpha_1\, ln\, x_{1i} + \alpha_2\, ln\, x_{2i} + \alpha_3\, ln\, x_{3i} + \alpha_4\, ln\ [\max\ (x_{4i}, 1 - D_{1i})] + \alpha_5\, D_{1i}\ (x_{5i}) + \alpha_5\, ln\, y_i + \xi_i - \tau_i \qquad (6.4)$$

Model for Technical Inefficiency

$$\tau_i = \eta_0 + \eta_1 z_{1i} + \eta_2 z_{2i} + \eta_3 D_{2i}\ (z_{3i}) + \eta_4 D_{3i}\ (z_{4i}) + \omega_i \qquad (6.5)$$

where '*ln*' refers to the natural logarithm, and the subscript *I (i- 1, 2, 3, . . . n)* refers to the i-th sample farm.

Specifications of exogenous variables

c_i = total cost (tk) for the i-th farm

x_1 = price (tk) of fingerlings per thousand

x_2 = cost (tk) for gher preparation per acre

x_3 = price (tk) of feed per kilogram for gher

x_4 = cost (tk) for disease control per acre of gher

x_5 = a dummy represented by D_1

D_1 = assume value 'One' if cost of disease control is positive and 'Zero' otherwise

y_i = total output (kg) of fisheries per acre

As mentioned earlier, 'kg' refers to kilograms and 'tk' to taka (Bangladesh currency).

Specifications for cost inefficiency variables

z_1 = age of the primary decision maker among the farming operators

z_2 = years of formal schooling of the primary decision maker among the farming operators

z_3 = a dummy represented by D_2

D_2 = assumes value 'One' if primary decision maker is the owner of the entire gher and 'Zero', otherwise

z_4 = a dummy represented by D_3

D_3 = assumes value 'One' if primary decision maker either received training on pisciculture or has extension contact, and 'Zero' otherwise

6.2.2 Outlining the theoretical basis for the cost frontier estimation

The theoretical underpinnings of this analysis, including model development, distributional specifications and methods of estimation, are described in chapter 3 (see sections 3.2.2 and 3.4.3).The distributional specifications proposed by Aigner et al., (1977) and Stevenson (1980) are widely used in empirical studies. This study, however, draws on Stevenson's (1980) model to explain cost efficiency in fisheries production. Results based on the likelihood ratio (LR) test lead us to assume a normal-truncated normal specification of error terms for predicting farm-specific cost efficiency. However, the mean of the inefficiency component (details are given in section 3.3.3 of chapter 3), can be calculated as:

$$E(\tau_i|\varepsilon_i) = \hat{\tau_i} = \mu_{*i} + \sigma_* \left[\frac{\varphi(-\mu_{*i}/\sigma_*)}{1-\Phi(-\mu_{*i}/\sigma_*)}\right] \qquad (6.6)$$

Then, the cost efficiency of the i-th farm, according to Battese and Coelli's (1988) formulation, is

$$CE_i = E\{\exp(-\hat{\tau_i})\,|\varepsilon_i\} \qquad (6.7)$$

$$= \left[\frac{1-\Phi\left(-\frac{\mu_{*i}}{\sigma_{*i}}+\sigma_{*i}\right)}{1-\Phi\left(-\frac{\mu_{*i}}{\sigma_{*i}}\right)}\right].\exp\left(-\mu_{*i}+\frac{\sigma_{*i}^2}{2}\right) \qquad (6.8)$$

where, $\mu_{*I} = (-\sigma^2_\tau \varepsilon + \mu\sigma^2_\xi)/\sigma^2$; $\sigma^2_{*I} = \sigma^2_\tau \sigma^2_\xi /\sigma^2$; Φ (.) refers to a standard normal cumulative density function, and φ (.) indicates the standard normal density function. It is worth mentioning that, prior to estimation, all input variables are normalized by the diesel prices faced by all farms to allow for neutral variations in the returns to scale parameter following Nerlove's (1963) recommendation (cited in Green, 1980), (for detail see section 3.5 of chapter 3).

Table 6.2: Maximum-Likelihood Estimates of the SCF Model for Fisheries Production with SRM in beel Dakatia

Variables	Notation	Parameters	Coefficients	Std. errors	t-ratios
Constant		α_0	1.0025 (1.8711)	0.4594 (0.4587)	2.1820***
Fingerling price	x_1	α_1	0.4436 (0.3559)	0.1024 (0.1054)	4.3305***
Gher preparation cost	x_2	α_2	0.1882 (0.2192)	0.0340 (0.0361)	5.5367***
Feed price	x_3	α_3	0.4939 (0.4734)	0.0906 (0.0997)	5.4527***
Disease control cost	x_4	α_4	0.0647 (0.0907)	0.0300 (0.0310)	2.1551**
Disease Dummy	D_1	α_5	0.3450 (0.3021)	0.1130 (0.1193)	3.0547***
Total output	y_l	α_6	0.5878 (0.485)	0.0379 (0.039)	15.495***
Inefficiency model					
Constant		η_0	-2.5812	1.2752	-2.0242**
Age	z_1	η_1	0.0196	0.0101	1.9320*
Years of schooling	z_2	η_2	0.0750	0.0344	2.1822**
Ownership Dummy	D_2	η_3	0.1525	0.1925	0.7926
Extension Dummy	D_3	η_4	-3.6036	1.8501	-1.9478*
Diagnosis statistics					
Sigma-squared		σ^2	0.4505	0.1300	3.4643***
Gamma		γ	0.8532	0.0438	19.4641***
Log-Likelihood			-60.5793		

*Note: *** significant at 1% level (p<.01)*
***significant at 5% level (p<.05)*
** significant at 10% level (p<.10)*

(Figures in parentheses are OLS estimates)

Source: Own estimation

Table 6.3: Maximum-Likelihood Estimates of the SCF Model for Fisheries Production with TRM in beel Bhaina

Variables	Notations	Parameters	Coefficients	Std. errors	t-ratios
Constant	x_0	α_0	2.7865 (2.6499)	0.3417 (0.3820)	8.1553***
Fingerling price	x_1	α_1	0.3799 (0.4227)	0.0763 (0.0876)	4.9767***
Gher preparation cost	x_2	α_2	0.0807 (0.1154)	0.0332 (0.0367)	2.4254**
Feed price	x_3	α_3	0.0602 (0.1152)	0.0977 (0.1041)	0.6160
Disease control cost	x_4	α_4	0.1014 (0.1119)	0.0302 (0.0354)	3.3531***
Disease Dummy	D_1	α_5	-0.2324 (-0.2405)	0.0803 (0.0904)	-2.8943***
Total output	y_i	α_6	0.4187 (0.4541)	0.0517 (0.0557)	8.1029***
Inefficiency model					
Constant		η_0	0.5044	0.2932	1.7204*
Age	z_1	η_1	-0.0016	0.0044	-0.3634
Years of schooling	z_2	η_2	-0.0075	0.0203	-0.3694
Ownership Dummy	D_2	η_3	-0.1262	0.1067	-1.1728
Extension Dummy	D_3	η_4	-0.4674	0.2142	-2.1818**
Diagnosis statistics					
Sigma-squared		σ^2	0.1048	0.0361	2.8999***
Gamma		γ	0.7214	0.1354	5.3262***
Log-Likelihood			-4.4855		

*Note: *** significant at 1% level (p<.01)*
*** significant at 5% level (p<.05)*
** significant at 10% level (p<.10)*

(Figures in parentheses are OLS estimates)

Source: Own estimation

6.3 Hypotheses testing and Decision Rules

6.3.1 Tests of hypotheses on inefficiency and pooled models for SCF analysis

This section recalls the fundamental rules and procedures involved in hypotheses tests regarding specifications of inefficiency and pooled models. The fundamental rules and procedures of the hypothesis test for the parameters of cost efficiency analysis are the same as those apply to the technical efficiency analysis in chapter 5, albeit the variables and their number are different. Therefore, estimates of log likelihood values, test statistics and critical values, along with degrees of freedom, differ between these two chapters. Since the number of variables is different, the null hypotheses differ accordingly. The following are the statements of null hypotheses in the order they usually appear:

a) H_0: $\gamma = \vartheta_0 = \vartheta_1 = \vartheta_2 = \vartheta_3 = \vartheta_4 = 0$, indicates that the inefficiency effects are absent in the stochastic cost frontier model. Therefore, the traditional average response model, the OLS, is appropriate for the stochastic cost frontier for the management system.

b) H_0: $\gamma = 0$, states that the inefficiency effects are not random. So, the variance of the inefficiency effects will also be zero if the parameter γ is zero; meaning the stochastic cost frontier reduces to a traditional mean response function.

c) H_0: $\vartheta_0 = \vartheta_1 = \vartheta_2 = \vartheta_3 = \vartheta_4 = 0$, specifies that the intercept and all the coefficients of the farm-specific variables are zero. In other words, the technical inefficiency effects have a traditional half-normal distribution with a mean equal to zero. Rejection of this null hypothesis indicates that the standard stochastic error component model is not appropriate for the half-normal distribution of the cost inefficiency effects (see Sharma and Leung, 1999).

d) H_0: $\vartheta_1 = \vartheta_2 = \vartheta_3 = \vartheta_4 = 0$, states that coefficients of all the explanatory variables in the inefficiency effect model are zero, meaning the cost inefficiency model follows the same truncated normal distribution with a mean equal to ϑ_0, as suggested by Stevenson (1980). It also implies that farm-specific and management variables are not able to influence the inefficiency effects significantly. Rejection of this null hypothesis indicates that the joint effects of all farm-specific and management variables on the inefficiency of cost are significant, although the individual effects of one or more of the variables may be statistically insignificant (Battese and Coelli, 1995).

These null hypotheses are tested using the generalized likelihood-ratio statistic, λ, as follows:

$$\lambda = -2\,[\ln\{L(H_0)\} - \ln\{L(H_1)\}] \qquad (6.9)$$

where $L(H_0)$ and $L(H_1)$ denote the values of likelihood function under the null (H_0) and alternative (H_1) hypotheses, respectively. Table 6.4 presents the test results of parameters of the stochastic cost frontier models for fisheries production with the SRM and TRM systems.

6.4 Presentation and Discussion of the Results

6.4.1 Estimated parameters of the models and fitness of the SCF models

Tables 6.2 and 6.3 present the maximum likelihood estimates of the parameters of the stochastic cost frontier for fisheries production with the SRM and TRM management systems. The signs of the coefficients of all the variables in the stochastic frontier models for both of the beels/management systems are as expected, with the exception of a negative estimate for beel Dakatia. This exception occurs not with any basic input variables, but with the dummy variable for zero observation and can be ignored. All the variables in both of the stochastic models are significant except one variable in the TRM system (in beel Bhaina). Again, the level of significance for all the significant variables is high (i.e., $p<0.01$), except for one variable in each of the models having a p-value of less than 0.05. These results indicate that the models truly represent the production regimes with both of the FCDM systems.

Table 6.4: Hypotheses tests and decisions

Null hypothesis	Log-likelihood value	Test statistic (λ)	Critical value ($\chi^2_{0.95}$)	Decision
Beel Dakatia (SRM)				
H_0: $\gamma = \vartheta_0 = \vartheta_1 = \vartheta_2 = \vartheta_3 = \vartheta_4 = 0$	69.365	17.572	11.911	Rejected
H_0: $\gamma = 0$	65.77	10.382	5.138	Rejected
H_0: $\vartheta_0 = \vartheta_1 = \vartheta_2 = \vartheta_3 = \vartheta_4 = 0$	67.405	13.652	9.488	Rejected
H_0: $\vartheta_1 = \vartheta_2 = \vartheta_3 = \vartheta_4 = 0$	66.237	11.316	7.815	Rejected
Beel Bhaina (TRM)				
H_0: $\gamma = \vartheta_0 = \vartheta_1 = \vartheta_2 = \vartheta_3 = \vartheta_4 = 0$	18.707	28.444	11.911	Rejected
H_0: $\gamma = 0$	7.565	6.16	5.138	Rejected
H_0: $\vartheta_0 = \vartheta_1 = \vartheta_2 = \vartheta_3 = \vartheta_4 = 0$	15.733	22.496	9.488	Rejected
H_0: $\vartheta_1 = \vartheta_2 = \vartheta_3 = \vartheta_4 = 0$	15.622	22.274	7.815	Rejected
Pooled model				
H_0: $\gamma = \vartheta_0 = \vartheta_1 = \vartheta_2 = \vartheta_3 = \vartheta_4 = 0$	127.945	28.802	10.371	Rejected
H_0: $\gamma = 0$	117.902	8.716	5.138	Rejected
H_0: $\vartheta_0 = \vartheta_1 = \vartheta_2 = \vartheta_3 = \vartheta_4 = 0$	127.188	27.288	9.488	Rejected
H_0: $\vartheta_1 = \vartheta_2 = \vartheta_3 = \vartheta_4 = 0$	125.659	24.23	7.815	Rejected
Test of Pooling Models (Functional Form: Cobb-Douglas				
H_0: Data can be pooled	-113.545	96.96	23.685	Rejected

Note: *Mixed $\chi^2_{v,\,0.95}$ values are taken from Table 1 of Kodde and Palm (1986).*

The study reveals that the most important factor in pisciculture is the fish seed (fingerling) and it carries a significant share of the total costs. Cost elasticity with respect to fingerling price is 0.4436 with SRM (in beel Dakatia) and 0.3799 with TRM (for beel Bhaina) and this is highly significant ($p<0.01$). These estimates indicate that fingerling price contributes more to the total cost of fisheries production with the SRM system than that with the TRM system, and this finding is consistent with the prevailing situation. The main variety of fisheries cultured in beel Dakatia is fresh water prawn (locally known as golda) and the price of prawn fingerling is substantially higher than the price of brackish water shrimp fingerling, the main variety cultured with TRM (in beel Bhaina). It is also evident from the statistical summary given in table 6.1, that on average, the difference between the fingerling prices of these two species is about tk. 1490.90 (per thousand fingerlings).

Feed requirement as well as feed type for different species of fisheries differ to a large extent and it has been reflected in the study results. In fact, feed provides the necessary indications of distinguishing alternative production environments as well as the nature of different species. However, with the SRM system (beel Dakatia), feeding emerges as the highest contributing factor to the total costs; in contrast, it is the least contributing with the TRM system (in beel Bhaina). The coefficients of feed are 0.494 and 0.060 against the SRM and TRM systems respectively. Meaning a one unit of extra expenditure on feed would add to about 0.5 units to the total cost with the SRM system, while this figure is much lower with the TRM system, only 0.06 units. One plausible reason may be the different food habits of the two major varieties of fisheries, freshwater prawn (*Macrobrachium rosenbergii*) is produced in beel Dakatia and brackish water shrimp (*Penaeus monodon*), cultivated in beel Bhaina. In a fish pond, a kind of organism is produced naturally; the shrimp consume it as food, but the prawn do not. The *Penaeus monodon* (shrimp)variety is believed to be omnivorous and farmers require to provide much less of external feed to this variety compared to the *Macrobrachium rosenbergii* (prawn) variety. This is certainly a great advantage for pisciculture with the TRM system; again, the price of adult shrimp and prawn do not differ as such.

Gher (fish pond) preparation costs are quite different in each of the management systems, in common with the feed price, indicating the existence of some dissimilar elements in the production environments. According to the estimated cost elasticity of gher preparation, gher preparation with SRM contributes 19% share, whereas this share is only 8% with TRM, to a 100% increase in total cost. In other words, gher preparation with the SRM system contributes to the total costs at a rate which is more than double the rate with TRM. One plausible reason may be the differing soil quality in the management systems. In the SRM system, the soil is relatively light and fragile in nature (when dried) because of its peat contents, so this soil is not suitable for building sustainable/strong gher dykes, which may be the cause of higher costs for building and repairing the dykes. Another plausible reason may be the high cost of land preparation within a gher. In the SRM system, land preparation is mostly dependent on costlier human labour instead of draft power, whereas relatively cheaper draft power is used with the TRM system.

The coefficients of cost the elasticity of disease control are quite low for both of the management systems, with the estimates of 0.0647 and 0.1014 for SRM and TRM respectively, indicating their minimal contribution to total costs. These estimates are significant at 5% and 1% levels respectively for SRM and TRM systems. However, in terms of contribution to total cost, they are very similar.

6.4.2 Estimated variables in the inefficiency model

Some of the inefficiency variables have the same sign in both of the management systems, while others do not, indicating contrary effects, as was also observed in the case of paddy production. The estimated coefficient of the *age* of the principal decision maker in the farming operation is positive in the SRM system, which indicates that younger farm operators are economically more efficient in fisheries production than the older operators, the reverse is true for the TRM system. In empirical studies, there is evidence of both types of findings for age. For example, the estimate with SRM conforms to the results observed by Battese and Coelli,1995; Parikh et al., 1995; Ajibefun et al., 1999; Coelli and Battese, 1996; Seyoum et al., 1996; Wadud and White, 2000; Rahman and Hasan, 2008. One plausible reason for this finding is that young farm operators are energetic and enthusiastically devote themselves to farming activities in order to bring prosperity in life. Meanwhile, the result with TRM is in line with the findings of Kalirajan (1984), Rahman and Rahman (2008). However, the age coefficient is not significant in the TRM system.

The coefficient of years of schooling is negative with the TRM system but positive with SRM. The negative estimate for education implies that inefficiency decreases with an increase in the level of education. The result with the TRM system is similar to the findings of Parikh et al., 1995; Rahman and Rahman, 2008; Alam et al., 2005; Yami et al., 2013; while the results with the SRM system match the results of Hussain (1989), (cited in Yami et al., 2013, p. 3936). Seemingly, the reason behind this result with the SRM system is that younger farm operators' levels of education are higher usually than those of the older operators, but often young farm operators' decisions are overruled by their seniors in the family, usually their fathers, who used to be the main operator. In addition, older people can sometimes be more conservative in adopting new technologies as well as modern farming practices.

Like age and years of schooling, the ownership dummy emerges with opposite signs for the two management systems—a negative sign with the TRM system and a positive with the SRM system. Generally, owner-tenants are more efficient than others since they are more enthusiastic and well-motivated in agricultural pursuits. The result for the SRM system is in agreement with the earlier findings of Kalirajan (1984), Rahman, (2003) and Rahman and Rahman (2008).

Finally, extension contact or training has a negative sign for both of the management systems and is also significant, indicating the importance of this variable in increasing the level of efficiency in pisciculture. This result is consistent with a large number of empirical studies on pisciculture, including those of Parikh et al., 1995; Alam et al., 2005; Rahman and Rahman, 2008; Singh et al., 2009.

6.4.3 Discussion of cost efficiency scores

The predicted cost efficiency scores for fisheries production with SRM system range from 0.2634 to 0.9533, with a standard deviation of 0.2753. These scores with TRM system vary from 0.4260 to 0.9504, having a standard deviation of 0.1281. These results show that the cost efficiencies of farms with SRM are much more widely dispersed than those with TRM. The mean cost efficiency score of fisheries production with SRM and TRM systems are 0.8068 and 0.7622 respectively. These scores indicate that cost of production could be reduced by approximately 20% and 24% for SRM and TRM systems respectively, keeping output level constant. Thus, the SRM system is marginally better than the TRM system in terms of cost efficiency of fisheries production.

6.4.4 Distributional patterns of cost efficiency score using coefficients of skewness and kurtosis

Coefficients of skewness and kurtosis are often used to identify distributional patterns of estimated scores which are subject to hypothesis testing. Table 6.5 shows the coefficients of skewness and kurtosis for efficiency scores for both of the management systems.

Table 6.5: Coefficients of skewness and kurtosis of cost efficiency ratings by management system

Particulars:	Skewness			Kurtosis		
FCDM systems	Coefficient of Skewness	Std. error	Z-value	Coefficient of Kurtosis	Std. error	Z-value
SRM	-1.728	0.170	-10.165**	4.154	0.338	12.299**
TRM	-0.752	0.197	-3.817**	-0.413	0.391	1.056

** Significant at 5% level

Source: Own calculation

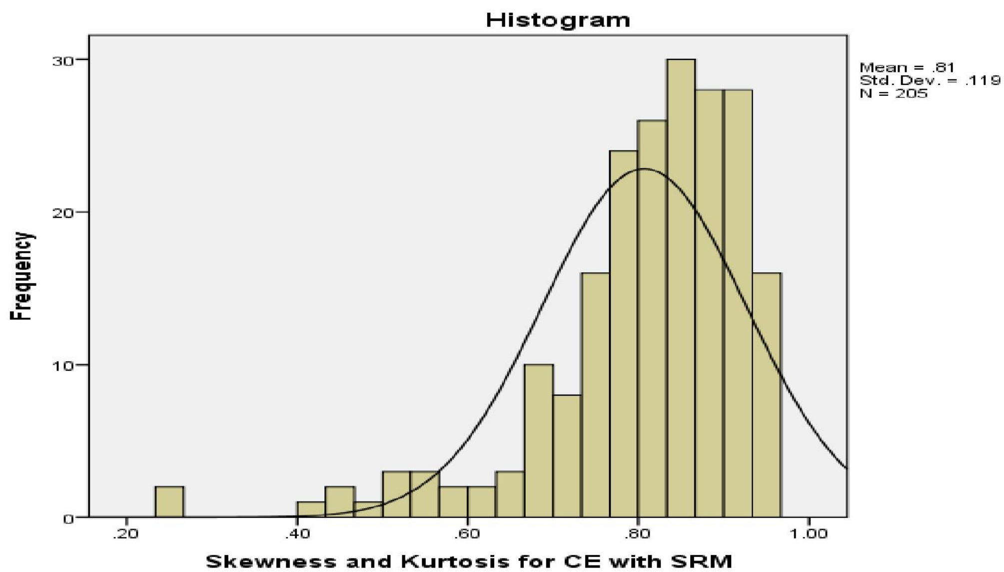

Figure 6.1: Histogram showing skewness and kurtosis for cost efficiency scores with SRM

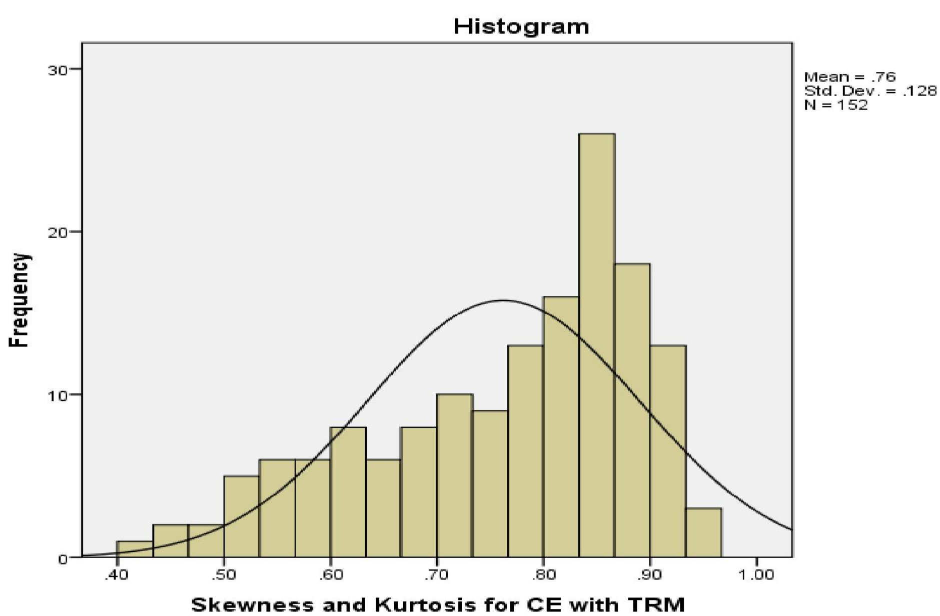

Figure 6.2: Histogram showing skewness and kurtosis for cost efficiency scores with TRM

The coefficients of skewness for cost efficiency ratings with both of the systems are negative, indicating that efficiency scores are skewed to the left. These scores with SRM are highly skewed, while they are moderately skewed with the TRM system. It can be seen from table 6.1 that the coefficients of skewness for cost efficiency scores with SRM and TRM systems are -1.728 and -0.752 respectively, and these are statistically highly significant. Since the efficiency ratings of the farms with SRM are more left-skewed than for its counterpart, a proportionately higher number of farms belonging to SRM are concentrated on the right of the mean efficiency score. In addition, the mean efficiency score of the farms with SRM is higher than that of the farms with TRM, as illustrated in the frequency histograms (see figures 6.1 and 6.2). These findings, however, indicate that the SRM system is significantly more efficient than the TRM for fisheries production.

On the other hand, coefficients of kurtosis show remarkably different distributional patterns for the cost efficiency scores with the management system; efficiency ratings for SRM are leptokurtic, whereas they are platykurtic with the TRM system. Table 6.5 reports that the coefficient of kurtosis for the efficiency scores of the farms belonging to SRM and TRM systems are respectively 4.154 and -0.413. From these coefficients, it can be deduced that farms with the SRM system are concentrated around the mean efficiency score; in contrast, farms with the TRM system are more widespread around the mean score. Thus, measures of the coefficient of kurtosis are in line with those of the coefficient of skewness. These facts are also evident from figures 6.1 and 6.2. The above findings indicate that performance of the two management systems is different in terms of cost efficiency of fisheries production.

6.4.5 Independent sample t-test and Levene's test for equality of variance for mean CE scores

After observing the distributional patterns of cost efficiency ratings, independent sample t-test in association with Levene's test for equality of variance for the efficiency scores was carried out in order to check whether the mean scores were statistically different from each other. Table 6.6 shows these test results by management system.

Table 6.6: Independent sample t-test and F-test for cost efficiency by system

Particulars	Overall efficiency statistics				Hypothesis tests	
Systems	Mean tech efficiency	Std. deviation	Maximum	Minimum	Levene's test for equality of variance	t-test for equality of means
SRM	0.807	0.275	0.953	0.263	5.901**	3.347***
TRM	0.762	0.128	0.950	0.426	(0.016)	(0.001)

**Significant at 5% level, ***Significant at 1% level
Source: Own calculation

The null hypothesis that the variances are homogeneous is rejected by Levene's test for equality of variance, F-test (F = 5.901 with 355 degrees of freedom), implying that equal variance does not hold true for the cost efficiency scores for SRM and TRM. Meanwhile, the independent sample t-test (t=3.383 with 355 degrees of freedom) indicates that the mean cost efficiency scores for the farms belonging to SRM and TRM are statistically different. Both of these tests are statistically significant at 1% level.

6.4.6 Effect size for independent samples t-test

In the case of a large sample, if the null hypothesis for an independent sample t-test is rejected, whilst the difference between mean values is small, it is recommended to further check this result. The measure of 'effect size' is usually used for this checking. Pallant (2011, p. 210) describes that in the case of large samples, a very small difference between groups has little or no practical/theoretical significance, even though the difference is statistically significant. From table 6.6, it is evident that the difference between the mean cost efficiency scores for the SRM and TRM systems is not big, and both F- and t-tests are statistically significant. Therefore, these results reveal the degree to which the means are associated with each other. In fact, 'effect size' (also known as 'strength of association') is a means of assessing the importance of the results obtained (Tabachnick and Fidell 2007, cited in Pallant, 2011, p. 210).

Among different size effect statistics, 'partial eta-squared' and 'Cohen's d' are most commonly used in empirical studies. The effect size statistic of 'partial eta-squared' takes the proportion of the variance of the dependent variable into account, which is explained by the independent (group) variable. 'Cohen's d', on the other hand, considers the standard deviation unit to report the difference between groups (Pallant, 2011). However, effect size statistics take a value of between 0 and 1. According to the guidelines proposed by Cohen (1988, p. 22), the strength of the size effects are classified as follows:

Table 6.7: Measurements of size effects: eta-squared and Cohen's d

Size category	Eta-squared (% of variance explained)	Cohen's d (standard deviation units)
Small effect	0.01 or 1%	0.2
Medium effect	0.06 or 6%	0.5
Large effect	0.138 or 14% (approx.)	0.8

Source: Pallant, 2011, p.210

However, eta-squared is more popular in social science and has been used in this analysis.

The formula for Eta-Squared, η^2, is given by

$$\eta^2 = t^2 / (t^2 + n_1 + n_2 - 2) \qquad (6.10)$$

where, t^2 is the square of the t-ratio obtained from the independent sample t-test; and n_1 and n_2 are the sizes of the samples involved.

Now, Eta-squared, $\eta^2 = (3.347)^2 / (3.347^2 + 205 + 152 - 2)$

$= 0.03$ or 3%

Table 6.7 shows that the eta-squared effect size lies between the small and the medium range, meaning only 3% of the variance in the efficiency ratings of fisheries production is explained by the management systems. That means the scores are not significantly different from one another.

6.4.7 Presenting the efficiency scores by frequency distribution and percentage share

Based on the range of cost efficiency score, the number of farms belonging to each system is classified by 5% and 10% class intervals in order to compare the competing management systems thoroughly. Then, frequency and the percentage share of farms are calculated for each of the management systems. Table 6.8 depicts the frequency distributions of the predicted cost efficiency scores and their percentage shares by 5% and 10% interval, and figure 6.3 presents a histogram of the percentage distribution of the scores for both of the systems. In addition, the line graph in figure 6.4 shows the patterns of variations. It is evident from the bar diagram that the distribution of scores is quite different for the two management systems. For example, 62.45% of the sample farms with SRM are at least 80% efficient, while this figure reduces to only 50.01% for TRM (see table 6.8). In contrast, a significantly higher percentage of farms from the TRM system fall below the 0.60 efficiency range, 14.48% farms with TRM compared to only 06.83% with SRM. In the mid-range of efficiency scores (0.60 to >0.80), the percentage of TRM farms exceeds SRM farms by 4.79%. These results indicate that the SRM system is slightly better than TRM in terms of cost efficiency for fisheries production.

Table 6.8: Frequency distribution and percentage share of TE scores by 5% and 10% class interval

Cost efficiency	Frequency (number of farms belonging to)				Percentage share with			
Particulars →	SRM (beel Dakatia)		TRM (beel Bhaina)		SRM system		TRM system	
	Class interval		Class interval		Class interval		Class interval	
Ranges ↓	5%	10 %	5%	10%	5%	10%	5%	10%
Below 0.50	6	6	5	5	2.93	3.29	3.29	3.29
0.50 - >0.55	3	8	10	17	1.46	3.90	6.58	11.19
0.55 - >0.60	5		7		2.44		4.61	
0.60 - >0.65	4	15	9	22	1.95	7.32	5.92	14.47
0.65 - >0.70	11		13		5.37		8.55	
0.70 - >0.75	16	48	15	33	7.80	23.41	9.87	21.05
0.75 - >0.80	32		17		15.61		11.18	
0.80 - >0.85	46	48	30	60	22.44	40.98	19.74	39.48
0.85 - >0.90	38		30		18.54		19.74	
0.90 - >0.95	43	44	15	16	20.98	21.47	9.87	10.53
0.95 and over	1		1		0.49		0.66	
Total	205		152		100.00	100.00	100.00	100.00

Table 6.8 also shows that the top three deciles consist of almost the same percentage of farms from each of the management systems, except the sub range of 0.90 - >0.95. This finding indicates that the two management systems have similar values with reference to the farms with the upper level of cost efficiency.

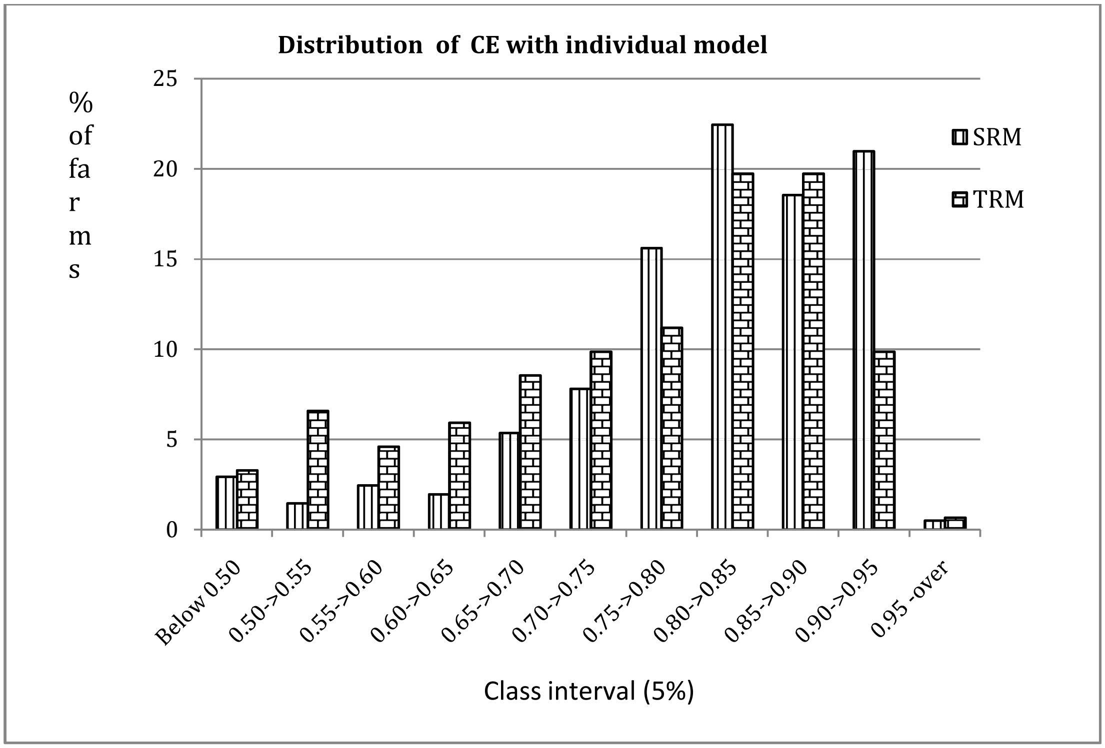

Figure 6.3: Histogram presenting percentage of farms based on score of CE by management system

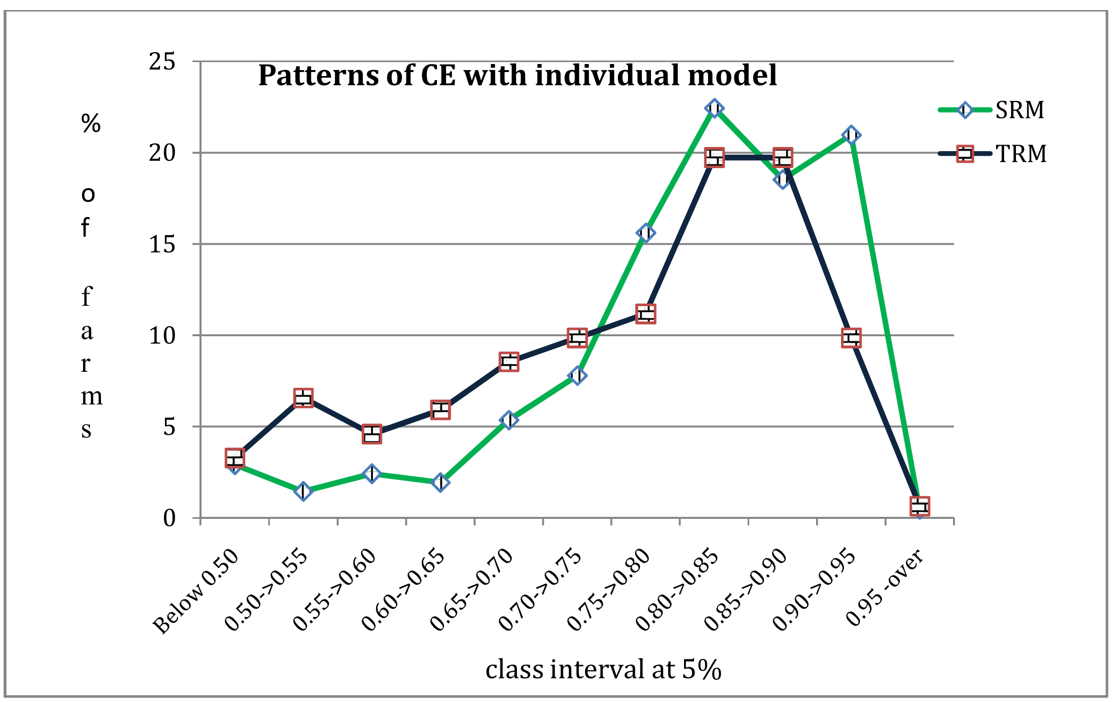

Figure 6.4: Patterns for cost efficiency scores by management system

6.5 Pooled Model for Estimating Cost Efficiency

6.5.1 Formulating a pooled model for fisheries production

The pooled model is another way of evaluating production organizations, where data from all individual (sub-sample) models are accommodated in a single model to analyse them simultaneously. However, an attempt was undertaken to form a pooled model for fisheries production with the SRM and TRM systems following the same principle used in developing the pooled model for paddy production (see section 5.5 of chapter 5). Equations (6.11) and (6.12) of the present chapter represent the pooled model for fisheries production with SRM and TRM management systems.

6.5.1 Empirical Stochastic Cost Frontier and Cost Inefficiency model for Pooled Data

$$ln\, c_i = \alpha_0 + \alpha_1\, ln\, x_{1i} + \alpha_2\, ln\, x_{2i} + \alpha_3\, ln\, [\max\, (x_{3i}, 1 - D_{1i})] + \alpha_4\, D_{1i}(x_{4i}) + \alpha_5\, D_{2i}(x_{5i}) + \alpha_6\, ln\, y_i + \xi_i - \tau_i \quad (6.11)$$

where '*ln*' refers to a natural logarithm and the subscript *I (i- 1, 2, 3, . . . n)* refers to the i-th sample farm.

Specifications of exogenous variables for the pooled model

c_i = total cost (tk) for the i-th farm

x_1 = price (tk) of fingerling per thousand

x_2 = price (tk) of feed per kilogram applied to the gher

x_3 = cost (tk) for disease control per acre of gher

x_4 = a dummy represented by D_1

D_1 = assumes value 'One' if cost of disease control is positive and 'Zero', otherwise

x_5 = a dummy represented by D_2

D_2 = assumes value 'One' if the beel is Dakatia, and 'Zero', otherwise.

Y_i = total output (kg) of fisheries

Meaning of the notations 'kg' and 'tk' are the same as those in equations (6.4) and (6.5).

Model for Technical Inefficiency (pooled data)

$$\tau_i = \eta_0 + \eta_1 z_{1i} + \eta_2 z_{2i} + \eta_3 D_{3i}\,(z_{3i}) + \eta_4 D_{4i}\,(z_{4i}) + \omega_i \qquad (6.12)$$

Specifications for technical inefficiency variables

z_1 = age of the primary decision maker among the farming operators

z_2 = years of formal schooling of the primary decision maker among the farming operators

z_3 = a dummy represented by D_3

z_4 = a dummy represented by D_4

D_3 = assumes value 'One' if primary decision maker is the owner of the entire paddy land and 'Zero', otherwise

D_4 = assumes value 'One' if primary decision maker either received training on pisciculture or has extension contact and 'Zero' otherwise

However, similar to the case of paddy production hypothesis test rejects pooling the sub-sample data for fisheries production and is not persuaded further.

6.6 Summary and Conclusions

This chapter illustrates cost efficiency of fisheries production as the principal indicator for evaluation of the FCDM systems. The mean cost efficiency scores of the farms belonging to SRM and TRM systems are 0.807 and 0.762 respectively, indicating that SRM system performs better on average than TRM. The efficiency scores with SRM are spread over a wider range, from 0.263 to 0.953, having a standard deviation of 0.275; in contrast, the range of the scores with TRM system is narrower, varying from 0.426 to 0.950 with a smaller standard deviation of 0.128. These results indicate that some farms with SRM performed extremely poorly. Findings show that cost of production could be reduced by approximately 20% and 24% for SRM and TRM systems respectively, keeping output levels constant. So, the SRM system is better than the TRM in terms of cost efficiency of fisheries production. These findings are justified by some statistical tests. The null hypothesis for the independent sample t-test of the efficiency scores with each of the systems has been rejected, along with Levene's test for the equality of variance. While the difference between the mean efficiencies is small and the value of Eta-squared is only 0.03. So, it can be deduced that the difference between the two mean efficiency scores has little practical significance.

The distributional patterns of the percentage share of the efficiency scores show that more than 62% of farms with SRM have at least a score of 0.80, whereas only 50% of farms with TRM qualify for this score range. The coefficients of skewness and kurtosis reinforce this finding. The coefficient of skewness and kurtosis are -1.73 and 4.15 for SRM system while these coefficients are -0.75 and -0.41 for TRM system in order. These findings also establish that the SRM system is more favourable to fisheries production compared to TRM system.

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CHAPTER SEVEN
YARDSTICKS OF PRODUCTIVITY AND PERFORMANCE

Chapter Structure

Objectives and Organisation of the Chapter

Chapter SEVEN

Yardsticks of Productivity and Performance

Objectives and Organisation of the Chapter

The previous two chapters (i.e., chapters 5 and 6) have used the estimates of technical efficiency and cost efficiency to evaluate the productivity performance of two flood control and drainage management (FCDM) systems. The present chapter, however, involves some standard yardsticks of productivity to assess the FCDM systems. The first section of this chapter provides the general idea about the yardsticks used in assessing productivity performance of the management systems. The second and third sections focus on the two fundamental yardsticks of productivity e.g., yield-gap and cost-gap respectively. Description of the two variant yardsticks of productivity e.g., potential yield increment (PYI) and potential cost saving (PCS), are presented in the fourth section; whilst section five illustrates another important yardstick, 'input usage cost', for paddy production only. The relationship between technical and cost efficiency ratings is examined using non-parametric correlation coefficients in section six, and finally, section seven presents the summary and conclusions.

7.1 Introduction

There are useful yardsticks of productivity that can be used to evaluate the relative performance of competing flood control and drainage management (FCDM) systems in terms of productivity performance of the farms with them. This study uses the yardsticks of productivity (YOP) in addition to productive efficiency estimates obtained from the econometric models (discussed in chapters 5 and 6). Several useful yardsticks of productivity (YOP) are chosen for the purpose of evaluating the FCDM systems, the SRM and the TRM. The present chapter, however, focuses on the concepts, measures and applications of these yardsticks. The basic yardsticks used here are ‘yield-gap’, and ‘cost-gap’, while the two variant yardsticks are ‘potential yield increment’ (PYI) and ‘potential cost saving’ (PCS). These two variant yardsticks are calculated respectively from yield-gap and cost-gap. ‘Yield-gap’ is often used in empirical studies for comparative analysis but is rarely used in combination with productive efficiency. The use of ‘cost-gap’ for efficiency analysis in empirical studies is rare, while the use of the variant concepts, potential yield increment and potential cost saving, are very rare. Another important yardstick 'input usage cost' mainly focuses on the performance of the FCDM systems in terms of efficiency in resources management. 'Input usage cost' is often used in a conventional way, but this study applies this yardstick adopting a unique technique.

However, the study exploits standard formulae for measuring these yardsticks of productivity following consistent methodological frameworks; while, measurement of these yardsticks involves manipulated data from the probabilistic sample survey and corresponding efficiency estimates from the econometric models on production and cost frontiers. In sum, this study employs three distinctive approaches, e.g., stochastic production frontier (SPF) analysis, stochastic cost frontier (SCF) analysis and yardsticks of productivity (YOP) to evaluate the FCDM systems.

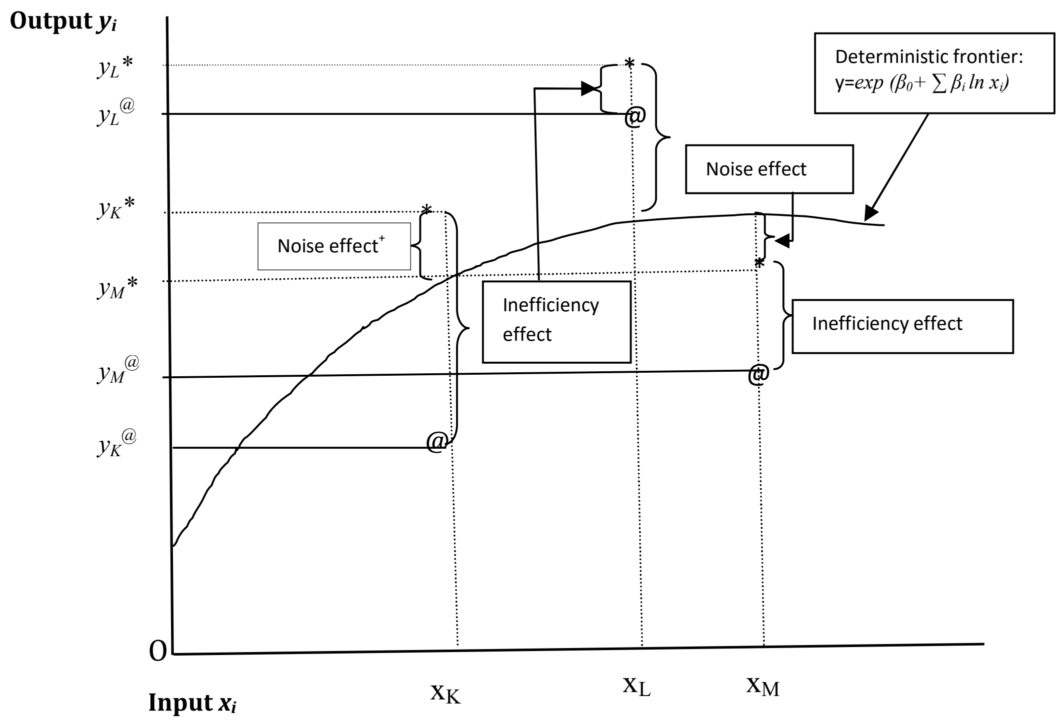
7.2 Formulae Development for Measuring Yield-gap

Herdt and Mandac (1981) introduced two well-known types of yield-gap which are often used in empirical studies (see section 3.10 of chapter 3). However, the present study develops a special type of yield-gap which can be termed as a variant of the second type of yield-gap mentioned by Herdt and Mandac (1981). This special type of yield-gap is assessed based on the extent of technical inefficiency of the farms under consideration. Inefficiency means less output compared to the output level if the farm were fully (perfectly) efficient. A farm’s observed output is referred to as the output with inefficiency, while the output level with perfect efficiency is termed as potential output. The difference between these two output levels of output is called yield-gap (between the two states of a farm). The important business here is to estimate the potential output level at the first place, which involves a complex estimation procedure. However, once the technical efficiency of the farm has been estimated, the job is almost done; then, the potential output can be computed with little mathematics. Theoretically, the extent of technical inefficiency is proportional to the yield-gap, and this inefficiency measure can be translated into 'efficiency gap' systematically, which in turn can be converted to 'yield-gap'.

7.2.1 From technical inefficiency to yield-gap

By definition, technical efficiency of a farm (say, the i-th farm) is the ratio of its actual output to the output that could be produced using the same input bundle by a farm which is fully efficient (Coelli et al., 2005, p. 244); hence, the measure of technical efficiency assumes a value between zero and one (see section 3.2.2(d) and equation (3.49) of chapter 3). A fully efficient farm produces the maximum possible amount of output and lies on the frontier, and its output is considered as frontier output for a given input vector. Such a farm's technical efficiency is one. So, any farm with a technical efficiency of less than one, is inefficient by definition. The extent to which the technical efficiency score falls short of one is termed as 'efficiency gap' (Dawson et al., 1991; Hadley, 2006).

Due to inefficiency or efficiency gap, a farm's output level remains below the frontier level (or the maximum feasible level of output). Accordingly, the measure by which observed output falls short of the maximum feasible output level is termed the yield-gap. This idea can be clarified with the help of the 'schematic diagram of the stochastic production frontier and output gap' (as described figure 3.2, section 3.2.2 (d) of chapter 3). The diagram is reproduced here for convenience. It illustrates the concept of yield-gap in association with the production frontier. As per the description of that schematic diagram, the asterisk sign (*) indicates frontier level output, and the at-the-rate sign (@) refers to actual output; therefore, the difference between these two output levels defines the yield-gap. An elaborate explanation of yield-gap can be presented involving equation group (3.15) (of chapter 3) in collaboration with the so-called actual output levels of three hypothetical farms *viz*, K, L and M used in explaining the diagram. The yield-gap associated with farm-K, (Y_{gK}), can be calculated using the following equation:



A reproduction of figure 3.2 from chapter 3**: Schematic diagram of the stochastic production frontier and output gap**

$$Y_{gK} = y_K{*} - y_K{@}$$
$$=[exp\ (\beta_0 + \sum \beta_K \ln x_K + \xi_K)] - y_K{@} \quad (7.1)$$

Likewise, yield-gaps for farm-L, (Y_{gL}), and farm-M, (Y_{gM}), can be defined respectively by

$$Y_{gL} = y_L{*} - y_L{@}$$
$$= [exp\ (\beta_0 + \sum \beta_L \ln x_L + \xi_L)] - y_L{@} \quad (7.2)$$

and

$$Y_{gM} = y_M{*} - y_M{@}$$
$$= [exp(\beta_0 + \sum \beta_M \ln x_M + \xi_M)] - y_M{@} \quad (7.3)$$

(Meanings of these notations are as described in section 3.2.2 of chapter 3).

Now, the formula for measuring the yield-gap, (Y_g), per unit of land can be given by

$$Y_{gi} = \left[\left(\frac{Y_{ai}}{1-E_{gi}}\right) - Y_{ai}\right] / L_i \qquad (7.4)$$

Where Y_{gi} = yield-gap of the i-th farm

Y_{ai} = actual output of the i-th farm

E_{gi}= efficiency gap for the i-th farm

L_i = land area of the i-th farm in a standard unit (e.g., acre)

The term $\left(\frac{Y_{ai}}{1-E_{gi}}\right)$ represents the maximum feasible output or frontier output of the i-th farm and is denoted by *(*Y_{fi}*).*

So, the formula for the yield-gap (Y_g) of the i-th farm can be simplified as

$$Y_{gi} = \left[Y_{fi} - Y_{ai}\right] / L_i \qquad (7.5)$$

7.2.2 The yield-gap ratio

When comparing yield-gaps of two (or more) production units or situations, the absolute difference between them is used as the basis for comparison; but this measure (absolute difference) often cannot give a clear idea about the relative size of the yield-gaps involved. For instance, say, yield-gap for farm-I and farm-II are 60 and 40 respectively, so the absolute difference is 20. Again, if the yield-gaps for farm-I and farm-II are respectively 1000 and 980, the difference is still 20. Thus, the absolute difference here is a vague measure and gives incomplete information about the relative size of yield-gaps, as well as the significance of the gaps. However, to make the comparison meaningful, an additional measurement is required which would provide a clear idea of the relative sizes of yield-gaps. Hence, the ratio between the yield-gaps with the highest one as the numerator can give a clearer idea about the relative size of the gaps, making the comparison more informative. Again, to provide a quick overview of relative sizes obtained from the ratios it requires a kind of classification which can be designed in the following way. By definition, the ratio of yield-gaps between two production units can take any value between unity and infinity. Assuming that the highest yield-gap is no more than twice of the size of the other yield-gaps i.e., the ratio is bounded by 2. Based on this range of values, the yield-gap difference can be classified into five categories, as presented in table 7.1.

Table 7.1 Classification of yield-gap ratios by their relative size

Categories *(Types of yield-gap)*	**Range of ratios** *(1 ≤ ratios ≤ ∞)*	**Relative size** *(of yield-gap)*
ND (No difference)	1	exactly the same
LD (Little difference)	1< ratio <1.25	very close to each other
MD (Medium difference)	1.25< ratio <1.50	not very close to each other
HD (High difference)	1.50 < ratio <1.75	Large gap
VHD (Very high difference)	ratio > 1.75	Very large gap

Source: Own calculation

The first category refers to 'No Difference' (ND) between the corresponding yield gaps and the ratio is one; the second category indicates 'Little Difference' (LD), and the ratio falls into the bottom range (i.e., 1< ratio <1.25); the next category refers to 'Medium Difference' (MD), having the ratio in the range of 1.25< ratio <1.50; while range of the ratios for the 'High Difference' (HD) and 'Very High Difference' (VHD) are respectively (1.50< ratio <1.75) and (ratio> 1.75). Intuitively, the range of these ratios would vary depending on the relative size of the corresponding yield gaps. A practical example is provided with table 7.2 that presents the average yield-gaps and the ratio of these gaps for SRM and TRM system. The difference between yield-gaps of the two management systems is 88.143. This difference is statistically significant at 5% level while Levene's test of homogeneity of variance is rejected at 1% level of significance.

Table 7.2: Yield-gap ratio alongside the yield-gaps for paddy production by management system

Particulars	Yield-gap (kg) in paddy production/acre						F-test	t-test
Systems	Average	Difference	Ratio	Max	Min	Std. deviation		
SRM	719.181	88.14	1.12	1672.21	161.43	330.32	15.78*** (0.000)	-2.06** (0.040)
TRM	807.324			2149.28	75.37	443.84		

*** Significant at 1% level
** significant at 5% level
(Figures in parentheses indicate the p-values)

Source: Own calculation

However, the ratio between the yield-gaps is only 1.123, which indicates that the extent of the yield-gap remains in the bottom range. Overall, the picture of yield-gap statistics shows that the SRM system is in a more favourable position compared to the TRM system.

7.3 Formulae Development for Measuring Cost-gap

'Cost-gap' or more appropriately 'excess cost' is assessed for the fisheries production with FCDM systems in the same way as 'yield-gap' in paddy production, although it (cost-gap) interprets the performance of a system/production unit in a reverse order. A cost efficient farm, by definition, produces a given amount of output with the minimum possible cost, which is called the frontier cost; here, the farm's cost efficiency score is one. When a farm's cost efficiency is less than one, it involves more cost than the frontier cost of producing per unit of output.

7.3.1 From cost inefficiency to cost-gap

In common with the 'technical efficiency gap', a farm's 'cost efficiency gap' is measured by how far the cost efficiency score is away from one. Accordingly, the cost-gap for the i-th farm is measured by the difference between its 'observed cost' and 'frontier cost'. The formula for measuring cost-gap (C_g) per unit of land is given by

$$C_{gi} = \left[C_{ai} - \left(1 - E_{gi}\right)C_{ai}\right] / L_i \qquad (7.6)$$

Where C_{gi} = excess cost incurred the i-th farm

C_{ai} = actual cost of the i-th farm

E_{gi}= efficiency gap for the i-th farm

L_i = land area of the i-th farm in a standard unit (e.g., acre)

The term $\left(1 - E_{gi}\right)C_{ai}$ represents the minimum feasible cost or the frontier cost of the i-th farm and is denoted by C_{fi}.

Thus, the formula for the cost-gap of the i-th farm can be simplified as

$$C_{gi} = \left[C_{ai} - C_{fi}\right] / L_i \qquad (7.7)$$

Like yield-gap ratio, cost-gap ratio can be calculated to compare two or more production units or situations. Table 7.3 shows the average amount of cost-gaps, as well as cost-gap ratio for fisheries production with the management systems. The average cost-gap involved in the fisheries production is higher with the TRM system than that with the SRM system by a margin of tk. 1897.673 per acre. Here, the null hypothesis of the t-test has been accepted, meaning these costs are not statistically different; again, Levene's F-test indicates that the assumption of the homogeneity of variance holds true.

Table 7.3: Cost-gap ratio alongside the cost-gaps for fisheries production by management system

Particulars	Cost-gap involved in fisheries production per acre						F-test	t-test
Systems	Average	Difference	Ratio	Max	Min	Std. deviation		
SRM	12542.71	1897.67	1.15	92516.8	257.28	13031.88	1.89 (0.170)	-1.33 (0.182)
TRM	14440.39			74256.36	600.15	13587.99		

*Figures in the parentheses indicate the p-values

Source: Own calculation

In line with the hypothesis test, the ratio between the cost-gaps for TRM and SRM is only 1.15, which suggests that the extent of the cost-gap falls into the bottom range. Thus, the SRM system appears to be better than the TRM system to some extent regarding fisheries production.

7.4 Potential Yield Increment and Potential Cost Saving

The concepts of 'yield-gap' and 'cost-gap' provide a general notion of the relative performance of production units. However, interpretation of these measurements in terms of 'potential yield increment' and 'potential cost saving' provide further understanding about the performance of the production units. Potential yield increment (PYI) and potential cost saving (PCS) are calculated against hundredweight (i.e., as a percentage). PYI refers to an additional output that could be produced if the farm were technically efficient, and PCS indicates an amount of cost that could be saved if the farm were economically efficient.

PYI and PCS are generally shown on average, i.e., considering all the farms together. However, these measures can be shown against different logical farm groups/segments, to provide a thorough understanding of the comparative performance of the production units/environments. So, this study assesses potential yield increment and cost saving for different farm groups along with the all-farm (i.e., on average) category. This group-wise performance evaluation considers three groups/categories of the farms based on the bottom (lowest), medium and upper (top) ranges of efficiency scores (where the bottom range covers score range up to below 0.60, middle range lies between 0.60 and below 0.80 and top range takes a score of 0.80 and above). These groups are constructed[1] by sorting the efficiency scores into ascending order and taking 20% of the farms from each range. Here the first group considers the bottom 20%; the second group the middle 20%; and the third group the top 20% of the farms with reference to efficiency score. Accordingly, each group selected from the farms belonging to SRM consists of 41 farms, while that of TRM system consists of 30 farms. It is noteworthy that the assessment of potential yield increment applies to paddy production, while potential cost saving relates to fisheries production. This kind of assessment for comparative performance evaluation is rare; a few studies, including Bravo-Ureta and Rieger (1991), attempted similar assessment, but in a restricted manner.

7.4.1 Measurement of potential yield increment

The formula for potential yield increment (PYI) is given by

$$PYI = \frac{Y_{ai} - \frac{Y_{ai}}{1-E_{gi}}}{Y_{ai}} \times 100 \tag{7.9}$$

(Notations bear the same meanings as before)

[1]Efficiency sores are categorised into three ranges (e.g., bottom, middle and top) in order to classify the farms, where the bottom range forms the first group, the middle range makes the second group and top range forms the third group. In this classification, each group takes 20% of all farms from each of the range. One may argue, why not 10% or 33% of all farms to be taken each of the range? Actually, the grouping with 20% of farms satisfies the large sample criterion, not only this, it is consistent with the theme and results of this study. However, if this classification considers 10% of the farms, it would not satisfy large sample criterion; again, if 33% of farms is considered, the groups might include farms with efficiency scores which are not consistent with the concept of bottom and/or top score range as far as the mean efficiency scores are concerned which lie between 0.76 and 0.80 points. For example, the bottom range here includes farms with efficiency scores of 0.71, which seems too high for a the first group (bottom category); whilst the top category (i.e., the third group) starts with an efficiency score of 0.82, which seems low; in contrast, with the 20%, the top category starts at 0.88, which looks reasonable. However, considering the mean efficiency scores, classification with 20% of farms maintains consistency, satisfying the large sample criterion.

Table 7.4 and figures 7.1 and 7.2 illustrate the potential yield increment based on observed output and technically efficient output for both of the management systems, SRM and TRM. A priori, the observed output level rises and PYI declines as the level of efficiency increases for both systems. It is interesting that the observed output levels for the bottom 20% group are higher with TRM farms than that with SRM; while, in the upper 20% group the observed output level is higher with SRM than that with TRM. These findings show an apparent mismatch between the actual output levels and corresponding farm group's efficiency ratings (as it may seem that higher output level always refers to the higher rating of efficiency). Recalling the percentage share of farms at different efficiency levels (in section 5.4.6 of chapter 5), it is seen that relatively a higher percentage (9.21%) of farms with TRM fall into the lower range of efficiency ratings while only 4.39% farm from SRM falls into this category. A conclusion can be drawn here from these findings that a higher output level does not always mean a higher efficiency rating. The same conclusion was drawn by Sharif and Dar (1996). Meanwhile, the level of observed and frontier output levels for the second (middle 20% farm) group are almost the same for both of the management systems, re-establishing the fact that farms belonging to the second group are more consistent than the two extreme groups (see table 7.4 and figure 7.1).

Table 7.4: Potential yield increment for paddy production with SRM and TRM by farm group

Particulars		Observed output (average)	Technically efficient output (average)	Group statistics (per hundredweight)			
Farm groups	Management Systems			Potential yield increment	Std. dev	F-test	t-test
Lowest 20% farms	SRM	1962.591	3165.277	62.550	14.828	0.028 (0.867)	-1.638 (0.106)
	TRM	2157.314	3605.757	68.280	14.189		
Middle 20% farms	SRM	2656.812	3358.925	26.481	3.343	0.440 (0.509)	-3.754*** (0.000)
	TRM	2612.204	3381.654	29.624	3.671		
Upper 20% farms	SRM	3472.984	3800.556	9.570	2.503	5.970**(0.017)	2.421*** (0.019)
	TRM	3197.356	3436.906	7.800	3.385		
All-farms	SRM	2670.44	3414.885	30.532	19.837	2.277 (0.132)	-1.259 (0.209)
	TRM	2657.78	3456.151	33.371	21.948		

Note: *** Significant at 1% level
** Significant at 5% level
(Figures in the parentheses indicate the p-values)

Source: Own calculation

The measure of potential yield increment shows a declining tendency as the efficiency level rises, a priori (see figure 7.3 and column 5 of table 7.4). Farms with the SRM system appear to be better off for two of the three groups in terms of output potential (fig. 7.3). The average potential yield increment with SRM is 30.53 (kg), whilst that with TRM is 33.37 (kg). This indicates that SRM outperforms TRM regarding the potential yield increment, on the whole.

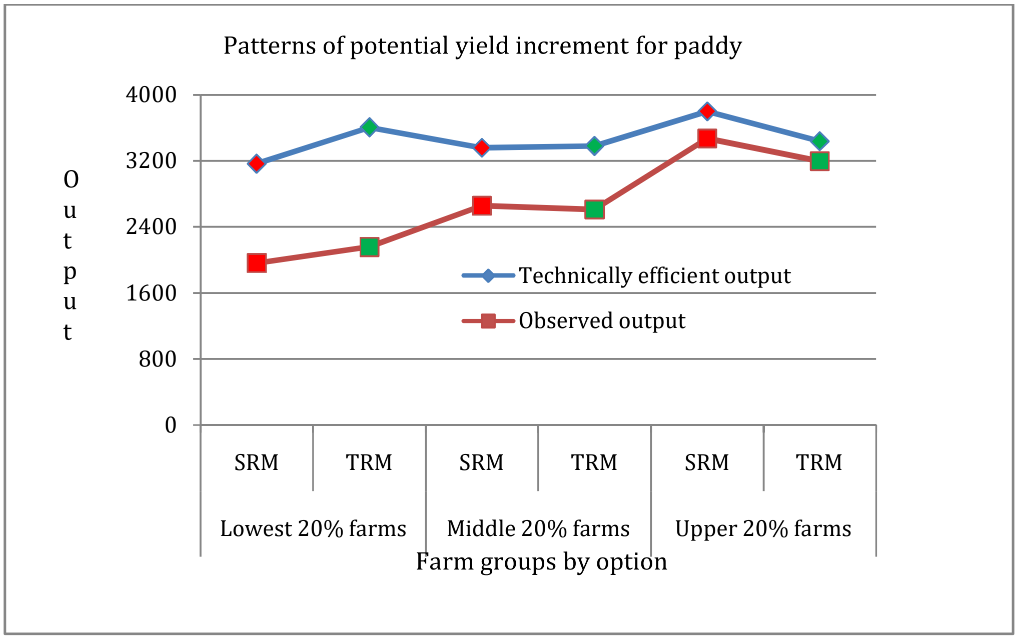


Figure 7.1: Patterns of potential yield increment for SRM and TRM by farm group

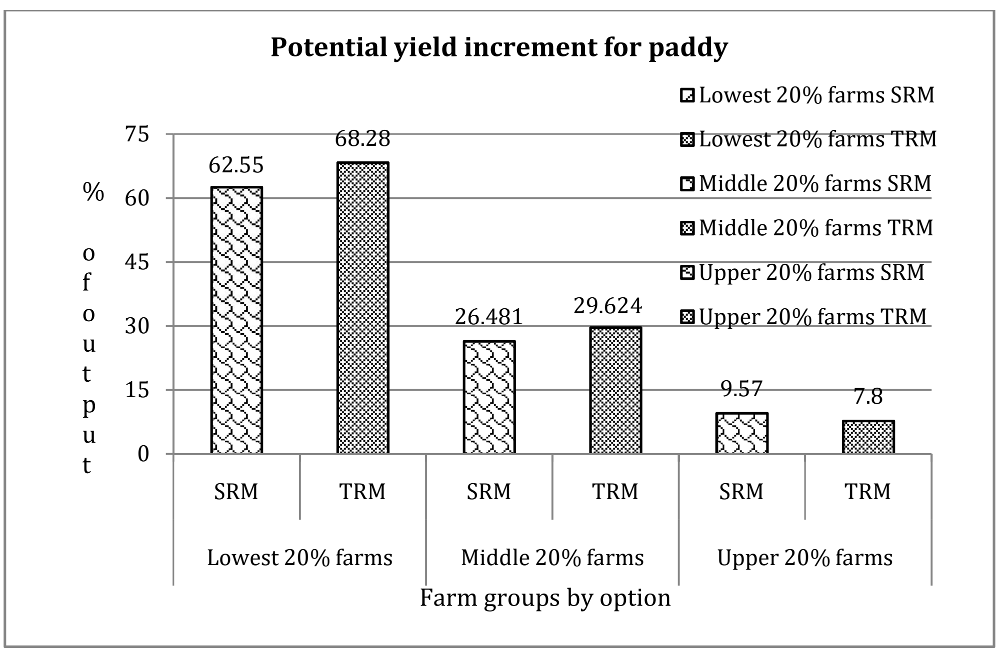


Figure 7.2: Rate of potential yield increment in paddy production by farm group and management system

7.4.2 Measurement of potential cost saving

The formula for potential cost saving (PCS) is given by

$$PCS = \frac{(1 - E_{gi})C_{ai} - C_{ai}}{C_{ai}} \times 100 \qquad (7.9)$$

(Notations bear the same meanings as before)

Table 7.5 and figures 7.3 and 7.4 illustrate the potential cost saving (PCS) and the relevant statistics about observed cost and economically efficient cost. The observed cost level decreases as the level of efficiency increases, a priori, for both of the management systems (figure 7.3). While this economically efficient cost takes declining trend with the TRM system and not with the SRM system. Interestingly, the average cost of fisheries production with SRM against the upper 20% farm group is higher compared to that with TRM, demonstrating an apparent mismatch between the cost of production and cost efficiency. Needless to mention that this is the second mismatch of its kind; the first one is between observed output level and technical efficiency (see section 7.4.1). However, looking back to the percentage share of farms based on cost efficiency scores (in section 6.3.6 of chapter 6), it is evident that relatively a higher share of farms with the SRM system belongs to the upper range of efficiency ratings compared to that of TRM system. This finding implies that higher cost efficiency does not necessarily mean a lower level of cost. On the other hand, it is evident from these assessments, and noticeable from figure 7.3, that as the efficiency level increases, the gap between the corresponding farm groups becomes narrow in terms of both observed cost and economically efficient cost.

Table 7.5: Potential cost saving for fisheries production with SRM and TRM by farm group

Particulars		Observed cost (average)	Economically efficient cost (average)	Group statistics (per hundredweight)			
Farm groups	Management system			Potential cost saving	Std. dev	F-test	t-test
Lowest 20% farms	SRM	70569.737	43675.932	37.931	12.076	11.67*** (0.001)	-3.189*** (0.002)
	TRM	80793.300	44083.551	44.795	5.676		
Middle 20% farms	SRM	57293.922	47583.451	17.083	1.320	12.663*** (0.001)	-7.440*** (0.000)
	TRM	48288.502	38315.989	20.462	2.217		
Upper 20% farms	SRM	43776.590	40616.357	7.198	1.394	4.841** (0.031)	-5.646*** (0.000)
	TRM	30975.133	27931.763	9.590	1.991		
All-Farms	SRM	59373.34	47914.29	19.325	11.937	5.901 (0.16)	-3.383*** (0.001)
	TRM	51388.60	39158.11	23.783	12.808		

Note: *** Significant at 1% level
** Significant at 5% level
(Figures in the parentheses indicate the p-values)

Source: Own calculation

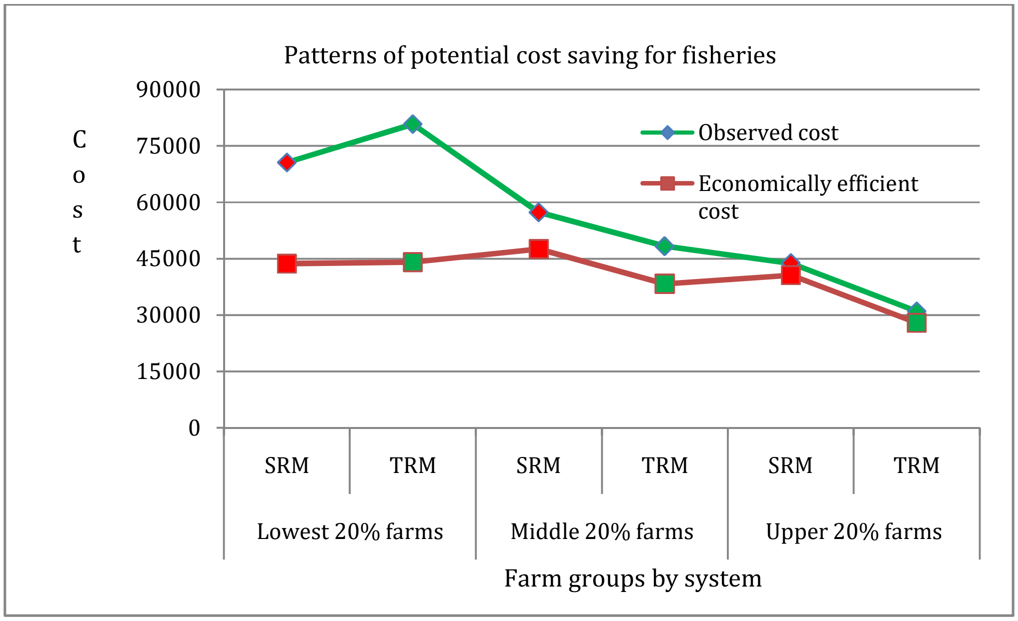


Figure 7.3: Patterns of potential cost saving by farm group and management system

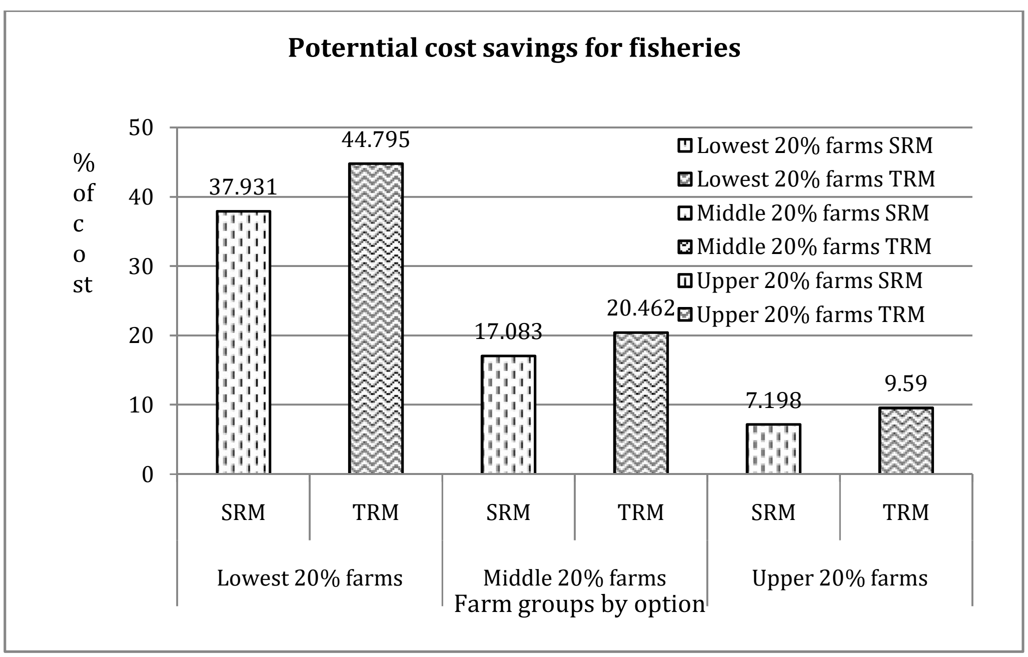


Figure 7.4: Rate of potential cost saving for fisheries production by farm group and management system

7.5 Input Usage Costs for Paddy Production

7.5.1 Input usage and the production environment

Input usage cost is an effective way of making a comparison between different production environments/organisations, and it has significant policy implications towards ensuring optimal resource utilization. Input requirement (or input usage cost) for producing a product is likely to differ from one production organisation to another due primarily to the production environment in which the product is produced. However, the extent of influence that a production environment exerts to determine the requirement for inputs (or finally input usage cost) varies, depending on the nature of the production environment as well as the type of the product. In agriculture, production environments by nature play a crucial role in determining input usage cost, particularly in crop production. This is because of different production environments that are endowed with different types of resources as well as resource utilisation capabilities. Contrasting input usage costs are likely if the same product is produced under different production environments. Production environments under different hydrological regimes are likely to be different; hence, contrasting input usage costs would evolve in producing the same crop. This can be attributed logically to the interventions or management systems that have caused the hydrological regimes. With the same understanding, this study takes into account the input usage cost in order to compare the two competing FCDM systems, SRM and TRM, in terms of their capability/efficacy in resource utilization.

7.5.2 Comparing SRM and TRM by input usage patterns with paddy production

In order to assess performance/efficacy of the management systems in terms of resource utilisation, this analysis starts with input usage patterns at the first place for different farm groups belonging to SRM and TRM for a thorough understanding. Table 7.6 shows input usages patterns for different farm groups per acre of land.

Table 7.6: Distributional share of input usage for paddy production with SRM and TRM by farm group

Particulars		Sub-grouping of the farms					
Inputs and output	Systems	Lowest 20%		Middle 20%		Upper 20%	
		Mean (Std. Dev.)	t-ratio (p-value)	Mean (Std. Deviation)	t-ratio (p-value)	Mean (Std. Deviation)	t-ratio (p-value)
Seed price (tk)	SRM	754.398 (187.419)	-4.198*** (0.000)	716.215 (229.940)	-4.729*** (0.000)	792.001 (273.726)	-2.308** (0.024)
	TRM	963.244 (231.423)		997.538 (270.033)		943.086 (270.850)	
Dewatering (lit)	SRM	35.401 (17.327)	8.336*** (0.000)	34.073 (16.848)	8.550*** (0.000)	31.759 (16.592)	7.282*** (0.000)
	TRM	11.294 (5.585)		9.533 (6.278)		10.762 (6.928)	
Land Prep cost (tk)	SRM	1401.395 (773.070)	1.657 (0.104)	1269.432 (754.640)	1.024 (0.310)	1407.063 (725.014)	2.537** (0.014)
	TRM	1188.251 (243.490)		1135.304 (312.314)		1071.129 (376.075)	
Urea (kg)	SRM	66.406 (18.971)	-9.670**** (0.000)	71.293 (20.456)	-5.968*** (0.000)	76.161 (27.370)	-5.457*** (0.000)
	TRM	122.670 (27.429)		113.640 (34.703)		116.000 (34.118)	
TSP (kg)	SRM	57.782 (19.992)	0.506 (0.615)	58.178 (19.854)	1.008 (0.317)	59.051 (22.964)	0.071 (0.944)
	TRM	54.594 (29.982)		53.178 (21.696)		58.617 (28.752)	
MP (kg)	SRM	30.085 (15.811)	2.071** (0.042)	30.890 (16.563)	2.154** (0.035)	30.949 (16.414)	2.686** (0.009)
	TRM	22.561 (14.115)		22.385 (16.255)		20.517 (15.821)	
Irrigation (lit)	SRM	10.367 (10.419)	-10.29*** (0.000)	7.902 (9.501)	- 11.396*** (0.000)	11.233 (9.270)	-7.469*** (0.000)
	TRM	42.862 (14.821)		41.500 (13.953)		34.788 (15.347)	
Labour (manday)	SRM	32.984 (7.052)	-3.968*** (0.000)	32.481 (7.195)	-3.519*** (0.001)	34.670 (7.569)	-2.851** (0.006)
	TRM	40.336 (8.541)		39.858 (9.691)		40.510 (9.691)	
Yield (kg)	SRM	1962.591 (294.810)	-2.563 (0.013)	2656.812 (296.558)	0.500 (0.619)	3472.984 (439.640)	2.373** (0.020)
	TRM	2160.647 (355.297)		2612.204 (417.564)		3197.356 (538.035)	

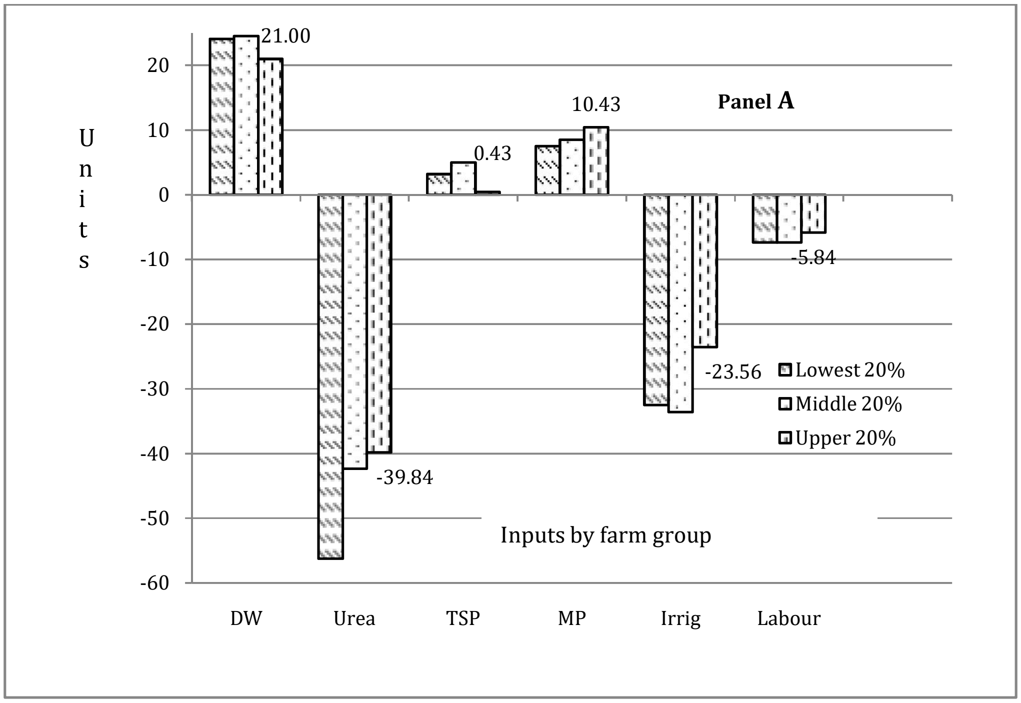
Note: *** Significant at 1% level
** Significant at 5% level
(Figures in the parentheses indicate the p-values)
Source: Own calculation

Results of statistical tests (t-test) reveal that the mean amounts of input usage for corresponding farm groups belonging to SRM and TRM are significantly different from each other in most cases, indicating varying levels of efficacy in resource utilization capacity. The yield levels with SRM and TRM systems are also different from each other, particularly for the first and third farm groups (the lowest 20% and the top 20%), but not so different with respect to the second (middle 20%) farm groups. The subgroups in the middle are, in fact, more consistent. However, these findings reconfirm that the two management systems render different production environments for paddy production.

Table 7.7: Mean difference between corresponding input shares with SRM and TRM by farm group

Particulars	Lowest 20%		Middle 20%		Upper 20%	
	Means	Mean Difference (SRM-TRM)	Means	Mean Difference (SRM-TRM)	Means	Mean Difference (SRM-TRM)
Inputs						
Seed	754.398	-208.846	716.215	-281.323	792.001	-151.086
	963.244		997.538		943.086	
Dewatering	35.401	24.107	34.073	24.540	31.759	20.997
	11.294		9.533		10.762	
Land Prep	1401.395	213.144	1269.432	134.129	1407.063	335.934
	1188.251		1135.304		1071.129	
Urea	66.406	-56.264	71.293	-42.347	76.161	-39.840
	122.670		113.640		116.000	
TSP	57.782	3.188	58.178	5.000	59.051	0.434
	54.594		53.178		58.617	
MP	30.085	7.523	30.890	8.505	30.949	10.432
	22.561		22.385		20.517	
Irrigation	10.367	-32.495	7.902	-33.598	11.233	-23.555
	42.862		41.500		34.788	
Labour	32.984	-7.352	32.481	-7.376	34.670	-5.840
	40.336		39.858		40.510	
Yield	1962.591	-198.056	2656.812	44.608	3472.984	275.628
	2160.647		2612.204		3197.356	

Source: Own calculation



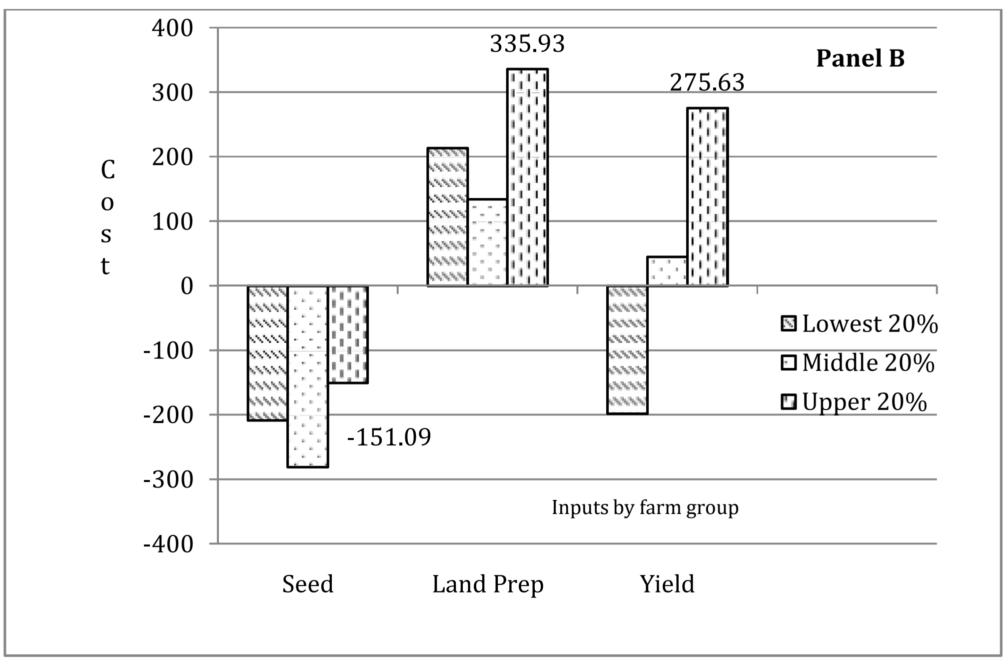


Figure 7.5: Comparing mean input usages between SRM and TRM by farm group (data levels shown against upper 20% farm group)

[Note: Figures are presented in two different panels because of dissimilar measurement units].

The mean differences regarding input counts between corresponding farm groups have been presented in table 7.7. Comparison between management systems can be made even by individual input item using this table. It is seen that farms with the TRM system require, on average, more urea fertilizer, irrigation and labour units compared to the farms with SRM; whereas, farms with the SRM system require more units of TSP, MP and dewatering compared to the farms with TRM. Seed cost is higher with TRM, while land preparation cost is higher with the SRM system. Panels A and B of figure 7.5 depict the mean differences of input usage between SRM and TRM management systems. It is evident (from figure 7.5) that the management systems are closer to each other for the upper 20% group in terms of input usage except the two inputs viz, land preparation and MP fertilizer (see figure 7.5).

7.5.3 Comparing SRM and TRM by input usage cost

The above attempts to compare the management systems involve multiple measurement units of input, which is a clumsy method of comparison as it is not possible here to place different types of units on the same scale. A uniform measurement unit is required to compare different management systems meaningfully. If all the input items are converted into a uniform unit, it would be easier to compare the competing management systems. This study, however, converts usages of inputs into monetary units and this is done by multiplying the applied quantities of different input items by their respective average prices. Table 7.8 presents input usages cost on average (i.e., for all farm-group) and for the third (top 20%) farm group against both of the management systems. These costs are calculated against per unit of land as well as per unit of yield. However, the logic behind considering only the third farm group is that the ultimate goal is to raise and maintain a higher efficiency level; therefore, the third (top 20%) group is more relevant in this context.

Table 7.8: Input usage costs per unit of land and per unit of output by farm group

Particulars	Cost of input usages							
	Upper 20% farm group				All-farm group			
Systems	SRM		TRM		SRM		TRM	
Inputs	Per acre of land	Per quintal of paddy	Per acre of land	Per quintal of paddy	Per acre of land	Per quintal of paddy	Per acre of land	Per quintal of paddy
Seed	792.00	22.80	943.09	29.50	732.35	27.42	991.25	37.30
DW	2064.34	59.44	676.61	21.16	2170.35	81.27	648.1897	24.39
Land Prep	1407.06	40.51	1071.13	33.50	1382.36	51.77	1088.34	40.95
Urea	1218.58	35.09	1856.00	58.05	1143.84	42.83	1885.76	70.95
TSP	2362.04	68.01	2344.68	73.33	2320	86.88	2139.2	80.49
MP	680.88	19.61	451.37	14.12	683.32	25.59	505.78	19.03
Irrigation	730.15	21.02	2187.12	68.40	640.25	23.98	2431.812	91.50
Labour	11094.40	319.45	12963.20	405.43	10556.8	395.32	13027.2	490.15
Total cost	**20349.44**	**585.94**	**22493.20**	**703.49**	**19629.27**	**735.06**	**22717.53**	**854.76**

Source: Own calculation

Figures 7.6 and 7.7 respectively depict the costs of individual input usages per acre of paddy farm and per quintal of paddy production against each of the management systems. These costs are calculated against the all-farm group (i.e., on average) and the third (upper 20%) farm group. Likewise, pie-charts 7.8 and 7.9 present the percentage shares of cost of different input items that contribute to the total cost of production against the all-farm group (i.e., on average) and the third (upper 20%) farm group for both of the FCDM systems. It is interesting that percentage share of cost of individual input items against per unit of land and per unit of output is almost the same for each management system. These findings imply that output level per unit of land with both of the management systems is very close to each other.

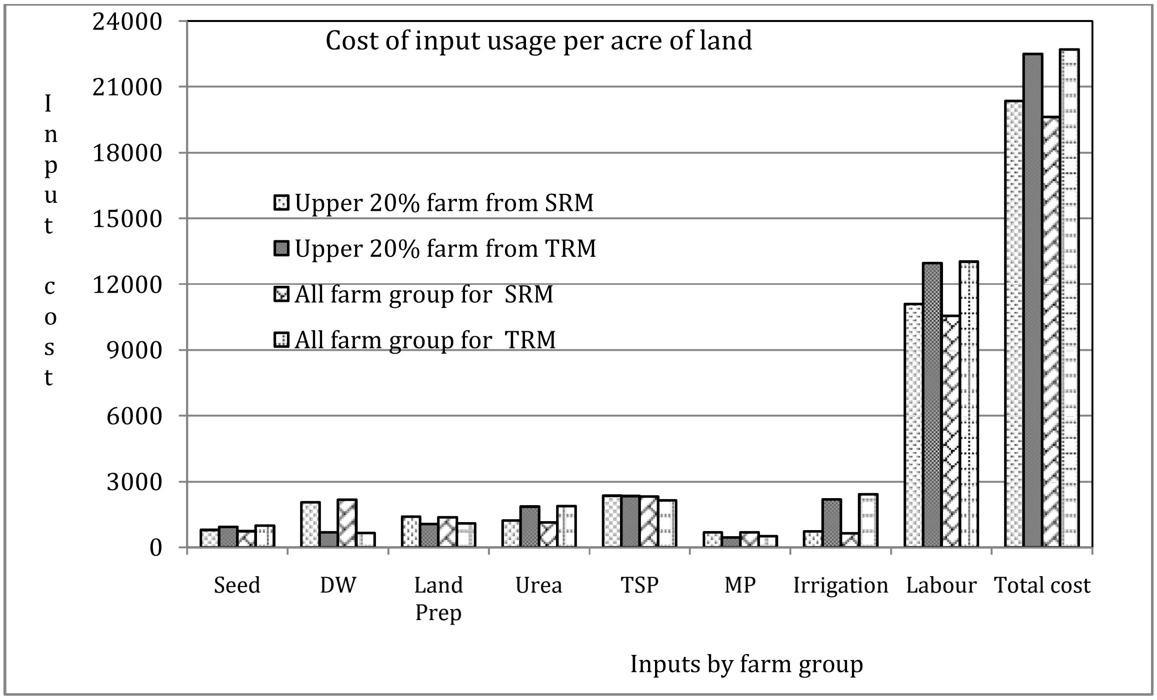


Figure 7.6: Average cost of individual input items per acre of land by farm group

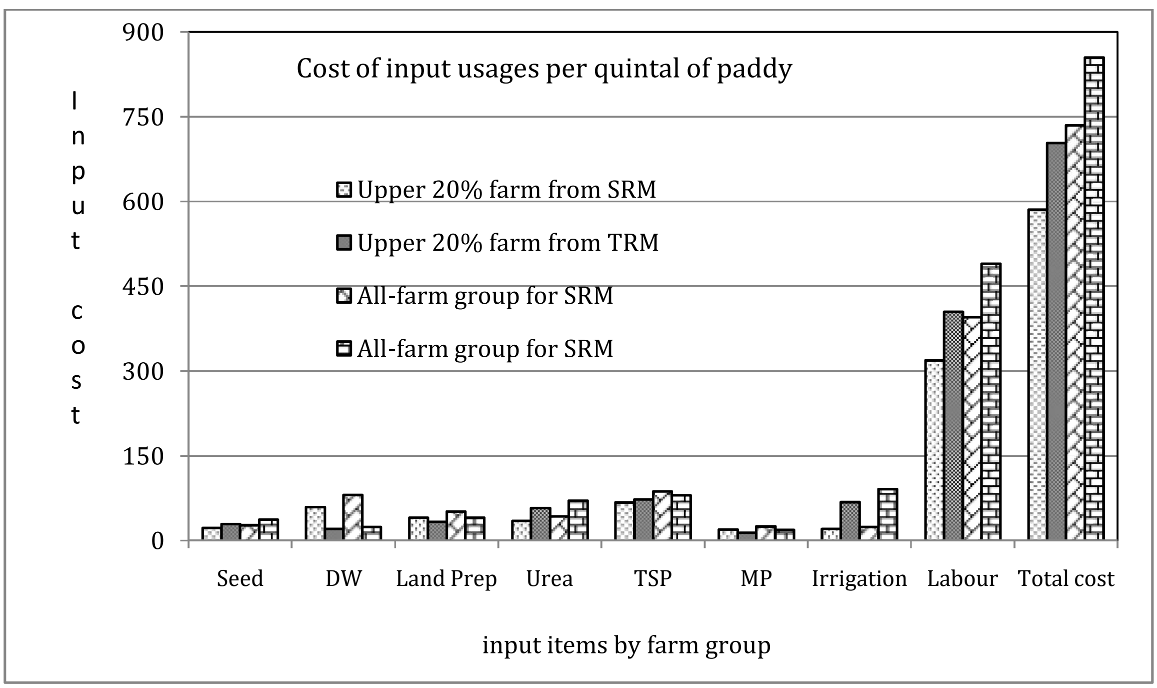


Figure 7.7: Average cost of individual input items per quintal of paddy by farm group

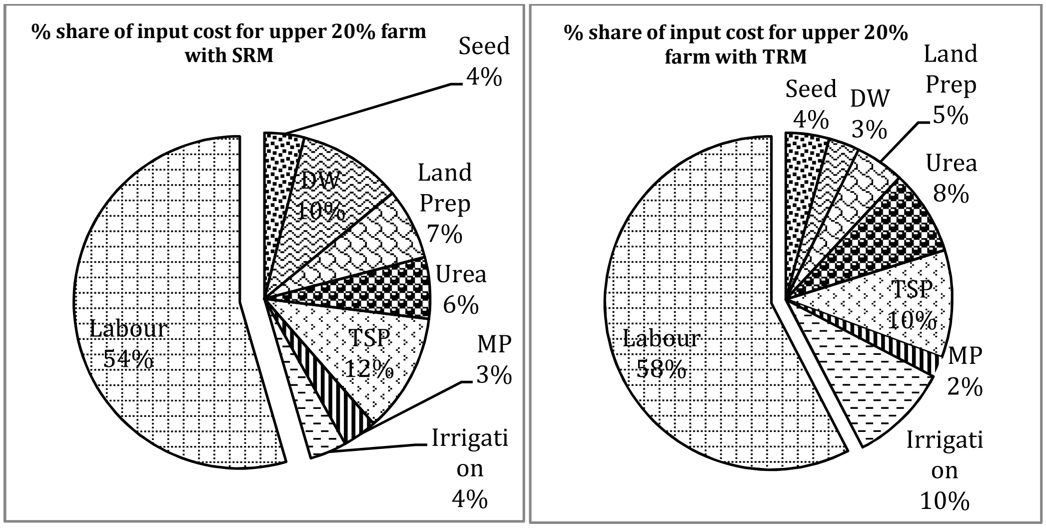


Figure 7.8: Percentage share of input cost of paddy production with SRM and TRM against the upper 20% farm group

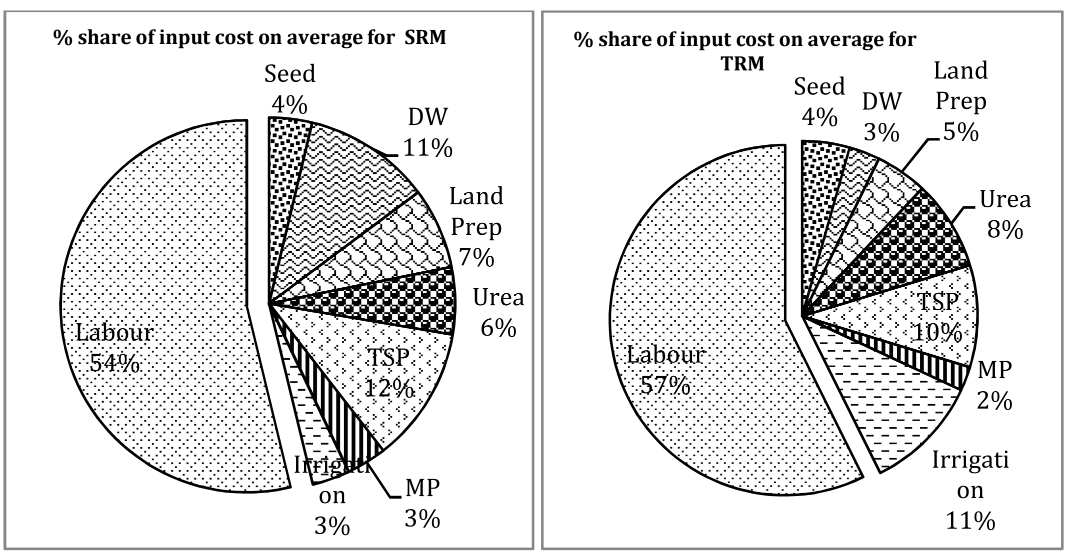


Figure 7.9: Percentage share of input cost of paddy production with SRM and TRM against the all-farm group (i.e., on average)

An overview of the above figures 7.8 and 7.9 is presented in table 7.9 in order to provide a total picture of the percentage share of individual input costs at a single glance.

Table 7.9: Percentage shares of input costs for paddy production with SRM and TRM by farm group

Particulars	Farm groups			
	Upper 20% farm group		All-farm group	
Input items	SRM	TRM	SRM	TRM
Seed	4	4	4	4
DW	10	3	11	3
Land Prep	7	5	7	5
Urea	6	8	6	8
TSP	12	10	12	10
MP	3	2	3	2
Irrigation	4	10	3	11
Labour	54	58	54	57

Source: Own calculation

The percentages of individual input costs in table 7.9 show that labour makes up more than half of the total cost of growing paddy in all cases, irrespective of farm groups and management systems; in contrast, MP fertilizer makes up 2-3% of the total cost. With both of the farm groups, the percentage of labour cost is higher for the TRM compared to that for the SRM system, while the reverse is true for MP fertilizer.

It is seen that corresponding cost figures for the same input item with both of management systems are very similar, except two input items, namely, dewatering and irrigation. For example, on average, dewatering makes up 11% of the total cost with the SRM system, while it is only 3% with the TRM system. The reverse is almost true for irrigation i.e., irrigation makes up 4% of the total cost with the SRM system, while it is 10% with the TRM system. These findings apply to the all-farm group. In the case of the third (upper 20%) farm group, similar findings have been recorded. The above findings lead to a dichotomous judgement over SRM and TRM systems, as far as environmental input items are concerned.

Turning to total cost, it is seen from table 7.8 that on average (i.e., the all-farm group) input cost per quintal of paddy with SRM and TRM systems are tk. 735.06 and tk. 854.76 respectively; while input cost per acre of land (for paddy production) are tk. 19629.27 and tk. 22717.53 with SRM and TRM in order. These findings reveal that on average, SRM system requires less cost compared to TRM for per unit of output and per unit of land in producing paddy.

Meanwhile, the upper 20% farm group records almost similar cost figures against per unit of output and per unit of land for paddy production with the competing FCDM systems. For example, cost of production per quintal of paddy are tk. 585.94 and tk. 703.49 with the SRM and TRM systems respectively, while the cost of production per unit of land are tk. 20349.44 and tk. 22493.20 in order. However, it is noteworthy that the average yield level of the third (upper 20%) group with SRM is significantly higher than that with TRM, unlike the all-farm group. The third (upper 20%) group establishes that the SRM system is clearly better than TRM system in terms of paddy production.

7.6 Nonparametric Correlation and Productive Efficiency Ratings

It is of interest to check if technical and cost efficiency scores of the same management system follow any pattern. To this end, these two types of efficiency scores with each management system are examined. This type of examination often involves non-parametric correlation coefficients. This study, however, calculates Spearman's rho on technical efficiency (TE) and cost efficiency (CE) scores for each of the management systems for the above purpose. Table 7.10 shows Spearman's rho for technical efficiency of paddy production and cost efficiency of fisheries production by management system.

Table 7.10: Spearman's rho for technical and cost efficiency scores by management system

Efficiency by crop type	Management systems	Spearman's rho	p-value
Between TE and CE scores (Paddy Vs Fisheries)	SRM	-0.054	0.444
Between TE and CE scores (Paddy Vs Fisheries)	TRM	-0.083	0.306

Source: Own calculation

Results show that there exists a negative correlation between efficiency scores of paddy and fisheries production with each management system. That means, there exist no specific patterns per se concerning technical efficiency and cost efficiency for either of the management systems. Hence, it can be deduced that it is very unlikely that a farm efficient in producing paddy is also efficient in fish production. However, the coefficient of correlation is very low and this relationship is not statistically significant.

7.7 Summary and Conclusions

This chapter has used several yardsticks of productivity including yield-gap and cost-gap in order to assess two competing management systems, the SRM and the TRM. Yield-gaps for SRM and TRM, are respectively 719.181 (kg) and 807.324 (kg) per acre of land, while cost-gaps are tk. 12542.713 and tk. 14440.386 in order. These gap-measurements indicate that the SRM system outperforms the TRM, in terms of the agricultural productivity for both crops. However, yield-gap and cost-gap ratios of with the SRM and the TRM are respectively 1.23 and 1.15. These ratios fall into the bottom range which implies that there exist differences between the SRM and the TRM systems in terms of performance in agricultural productivity but the extent of these differences is narrow.

Like yield-gap and cost-gap, potential yield increment (PYI) and potential cost saving (PCS) demonstrate that the SRM system performs better than TRM in agricultural production. On average (i.e., for the all-farm group), PYI measures are 30.532 and 33.371 for the SRM and TRM systems respectively. These measures for the three farm groups viz, bottom, middle and top 20% farms, are 62.550, 26.481 and 9.570 respectively with SRM, and 68.280, 29.624 and 7.800 with TRM. The potential cost saving (PCS) for the SRM and TRM systems, on average (i.e., for the all-farm group), are 19.325 and 23.783 respectively. These measures for the bottom, middle and top 20% farm groups are, respectively, 37.931, 17.083 and 7.198 with SRM, and 44.75, 20.462 and 9.590 with TRM. These findings regarding PYI and PCS make it clear that, in most cases, the SRM system marginally outperforms TRM.

In terms of input usage cost, labour has appeared as the most expensive input in paddy production, making up more than 50 percent of the total cost; in contrast, MP makes up about 3% of the total cost of production irrespective of farm groups and management systems. However, the most contrasting input items between the management systems are dewatering and irrigation. On average, dewatering constitutes around 10% of the total cost with the SRM system and only 3% with TRM; whereas, irrigation makes up around 3 % of the total cost with SRM and 11% with TRM irrespective of farm groups.

The cost of production per quintal of paddy with the SRM system is less than that with TRM on average (for the all-farm group). These costs are tk. 735.06 and tk. 854.76 for SRM and TRM respectively. On average (for the all-farm group), the total cost of inputs applied per acre of land with SRM and TRM systems are tk. 19629.27 and tk. 22717.53 respectively, while for the upper 20% farm group these are tk. 20349.44 and tk. 22493.20. It can be seen from these statistics that the difference between costs with SRM and TRM is around two thousand taka, irrespective of the farm group. However, for both of farm groups, this cost is higher for the TRM system, which places the rank of TRM behind SRM in terms of productivity performance in paddy production.

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CHAPTER EIGHT
SUMMARY AND CONCLUSIONS

Chapter Structure

Objectives and Organization of the Chapter

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8.2 The Research Design and Related Issues

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Chapter EIGHT

Summary and Conclusions

Objectives and Organization of the Chapter

The primary objective of this chapter is to provide a brief description of the main points of the present research work. This chapter also discusses some important aspects of the study, including limitations of the work, policy recommendations, contribution to the production of knowledge and future researches worthy of consideration. In the first two sections, the background of the study and research questions are recapitulated. Section two briefly describes the analytical techniques and sampling methods of data collection; section three explains how these research questions have met the objectives of the study. Policy recommendations and the scenario of the action plan are presented in section four; the subsequent two sections report on contributions to the production of knowledge and limitations of the study respectively. The conclusion of this study is presented in section seven and finally, section eight outlines the framework of future researches.

8.1 Introduction

Going beyond the boundary of conventional approaches to evaluating flood control and drainage management (FCDM) systems that often involve assessment of flood frequency and/or flood protection potential from an engineering perspective, this study has carried out this evaluation from the perspective of productive efficiency in agriculture. To the best of our knowledge, there is little or no works that evaluated FCDM systems based on the estimation of productive efficiency as well as the level of productivity in agriculture. In fact, there is a gap in the literature of performance evaluation which is that previous studies evaluated flood control and drainage management systems based on the capability of a system to protect an area from flooding, while neglecting the system's contribution to the productivity of the production units involved. This study, however, has addressed the gap in the literature of performance evaluation taking productivity of agricultural farms into consideration. Two competing flood control and drainage management systems—the Silt-dredging and Regulated-drainage Management (SRM) and the Tidal River-basin Management (TRM)—have been operational for about 15 years in the Southwest coastal zone of Bangladesh. These two systems were implemented in order to save crops from flooding and waterlogging problems and then to enhance agricultural productivity. It is noteworthy here that there was a debate over the appropriateness of these FCDM systems. However, it is expected that this study has contributed towards resolving the long-standing debate about the FCDM systems.

This study has added knowledge to the literature on flood management in several ways, in addition to addressing the gap in the literature. For instance, the Tidal River-basin Management (TRM) is absolutely a unique system from different perspectives (e.g., it is a low-cost natural FCDM system and counteractive to relative sea level rise (see FGD report in Appendix 4); most importantly, it (TRM) solves flooding and waterlogging problems in an environmentally friendly way (Tutu et al., 2009). This system evolved from the indigenous knowledge and wisdom of the people of the coastal zone of Bangladesh. It is noteworthy here that the TRM system under consideration is a blend of traditional practices and modern technology. Hence, this study has compared this unique system with a technology-fixed conventional system and thereby has widened our understanding of natural flood defence systems. Furthermore, the study area is considered to be very special because of its uncommon topographic features in terms of location and drainage network. Again, the interventions have added some extra features to the study area. This is why a rare variable, 'dewatering' has been included in the frontier models to represent the area. Turning to the methodological framework, a novel concept, the 'yield-gap ratio' has been developed to help better understand the relative importance of the yield-gaps. Thus, this work has contributed to the growing body of literature on flood management, and also to the literature of performance evaluation from different perspectives.

At the outset, the study formulated several research questions and sub-research questions based on the research problem (Chapter 1). Methodologies to answer the research questions were formulated drawing on similar empirical studies and guidance received from the literature review (Chapter 2). Hence, the two dominant crops in the study area—paddy and fisheries— were taken into account. Theoretical underpinnings of the methodologies are illustrated along with relevant concepts (Chapter 3). Primary data for this analysis were collected adopting multi-stage probabilistic sampling method (Chapter 4). Based on the theoretical underpinnings of the methodologies several econometric models were developed and estimated with stochastic frontier analysis (SFA) in order to compute relevant estimates of agricultural productivity (Chapters 5 and 6). Apart from these econometric models, several standard formulae were formulated to measure different types of yardsticks of productivity (Chapter 7). After an elaborate discussion of the findings and their implications in chapters 5, 6 and 7, this study uses its final chapter (Chapter 8) to conclude the research work. The main purpose of chapter 8 is to present all important findings briefly and draw an overall conclusion, then propose recommendations in this regard. The following section, however, starts with re-engaging the research questions in order to demonstrate how the goals and objectives which shaped this work have been followed through.

8.2 The Research Design and Related Issues

8.2.1 The main points of the research questions

The study required to answering five research questions and several supplementary or research sub-questions in order to address the objectives. The first two research questions ask for the productivity performance of the FCDM systems in terms of productive efficiency of the farms producing paddy and fisheries with them. Two distinctive types of efficiency scores, namely, technical efficiency and cost efficiency, have been estimated respectively for paddy and fisheries production based on the behavioural assumptions of the production process. Efficiency scores are, indeed, reliable indicators in the discourse of performance evaluation (Reinhard, 1999, p. 3; Kalirajan and Shand, 1999; Schmidt and Lovell, 1980). The research sub-questions in this connection inquire into the relative contribution of individual input items to output and cost of production. In fact, these are the estimated coefficients of the input variables. These estimated coefficients (or partial elasticities) are very useful in assessing different production environments. Besides, returns to scale (RTS), the most commonly used criteria for assessing a production system is calculated here.

The next two research questions inquire into the yield-gap for paddy production and cost-gap for fisheries production respectively; meanwhile, the associated research sub-questions asks for 'potential yield increment' (PYI) and 'potential cost saving' (PCS) in order. These measures reflect the relative position of the management systems, SRM and TRM, from two different perspectives. Yield-gap and potential yield increment consider the management systems from the total output point of view, while cost-gap and potential cost saving take them from the standpoint of total cost.

The last research question seeks to know input usage cost for paddy production with each of the management systems. Input usage cost has been considered here against per unit of output as well as per unit of land on average (i.e., based on all-farms) against each of the management systems. Besides, input usage cost has also been calculated against the third (upper 20%) farm group because of this group's important policy implications.

8.2.2 Econometric models and analytical techniques in brief

This study has developed a number of econometric models in order to address some of the research questions and sub-questions particularly the first two questions. These econometric models have been estimated with the stochastic frontier analysis (SFA) using the maximum likelihood (ML) method. There are alternative functional forms of the econometric model and specifications of the analytical technique. For example, an econometric model can take Cobb-Douglas or translog or other functional forms; meanwhile, a stochastic frontier model may incorporate an inefficiency model or not (i.e., remain as an error component model). Moreover, an inefficiency model can assume any of the four distributional specifications, namely, half-normal, exponential, truncated-normal and gamma distributions; while there are two distinctive procedures, e.g., single-stage and two-stage, for estimating stochastic frontier and inefficiency models. However, these alternative functional forms, specifications and procedures have been checked through statistical tests and treatments in compliance with underlying theories and assumptions and this study has thereby selected the appropriate ones from the alternatives. Finally, this study has applied the Cobb-Douglas functional form for stochastic frontier models assuming truncated normal distribution for inefficiency effects and adopted the single-stage procedure in estimating the parameters. The remaining research questions (i.e., other than the first two) have been addressed with different types of yardsticks of productivity (YOP) and these have been calculated using standard formulae.

8.2.3 Methods data collection

Data for the present research work were collected following a probabilistic sampling techniques. The study area consists of two depressed areas (locally known as *beel*), and these are located within the KJDRP command area. In selecting the farm households from the study area, multistage sampling procedures were used, maintaining the principle of proportionality for a representative number of elements against each area. Initially, each beel area was divided into upland and lowland parts, according to the elevation of the beel bed, and then stratified random sampling techniques were applied to select villages from each (upland and lowland) part of the two beels. A total of 14 villages were chosen out of 41 villages situated within or around the two beels. Farm households from each sampled village were again stratified into small, medium and large groups based on land holdings, following the classification used by the Bangladesh Bureau of Statistics (BBS); however, with some adjustment considering the reality of the study area. In other words, the sample households were selected through a series of stratified random sampling and simple random sampling where applicable.

Questionnaires for this study were designed after intensive literature review and extensive discussion with some experienced and educated farmers about farming practices and the specific impact of the FCDM systems on agriculture, keeping in mind the stochastic frontier analysis to be used for estimating the econometric models. Two sets of questionnaires were prepared, one for paddy and one for fisheries production.

A team of trained enumerators were appointed to collect data using structured questionnaires. The researcher himself administered the whole process of data collection and he was assisted by a coordinator. Basically, this study followed a face-to-face interview technique to collect primary data. A sample survey of 357 (three hundred and fifty seven) households during the production year 2011/2012 were taken into final consideration. From beel Dakatia, a total of 205 households were taken into consideration, of which 123 (or 60%) were from lowland areas and 82 or (40%) from upland areas; the sample sizes from upland and lowland areas for beel Bhaina were 99 (or 65%) and 53 (or 35%) respectively, comprising a total of 152 samples. Again, stratum (group) wise distribution of sample households against each area was maintained following the proportionate distribution of farm households found in each stratum. It is worth mentioning that ethics of data collection were fully maintained. As part of the ethical consideration, the respondents were informed of the purpose of this data before each session of data collection and their queries regarding this study were also answered with due respect.

8.2.4 Dealing with the research questions

Maximum likelihood (ML) estimates of the stochastic production and cost frontiers have provided answers to the first two research questions, whilst answers to the rest of the research questions have been extracted from manipulated survey data and productive efficiency scores using standard formulae. In addition, answers to some of the supplementary questions have been available from descriptive statistics of the survey data since this study pursued probabilistic sampling techniques for household survey.

In estimating econometric models with stochastic frontier analysis (SFA), there appear several types of alternative techniques at different stages; hence, this study has accepted those techniques that are consistent with underlying theories and assumptions and at the same time, provide unbiased and efficient estimates. For example, between the single-stage and two-stage approaches, the former complies with the underlying assumption and has been used in the analysis. SFA can assume any of the four distributional assumptions for inefficiency effects; however, this study tried two of the widely used assumptions, namely, the half normal and the truncated normal, and selected the latter as it was appropriate for the data set. Several functional forms can accommodate the econometric models under consideration; hence, it is recommended to try all possible functional forms in order to see the results before choosing a functional form (Bravo-Ureta and Pinheiro, 1993). Apart from the hypothesis test, these results are taken into consideration in choosing the appropriate functional from. This work, however, has tried out the most commonly used functional forms in the frontier analysis, the Cobb-Douglas and the translog, before selecting the Cobb-Douglas form. On the other hand, among the alternative approaches to deal with zero observations, the dummy variable approach provides unbiased estimates, since it is statistically sound (Battese et al., 1996; Battese, 1997), and the present analysis has followed this approach. As mentioned earlier, estimates from the maximum likelihood method have been considered in drawing the conclusion of this work. For the purpose of estimation, the study used specialized software FRONTIER 4.1, developed by Coelli (1996a).

In addition to the above mentioned estimation methods, this work has involved a number of standard formulae (described in chapter 7) to measure various yardsticks of productivity e.g., yield gap, cost gap, potential yield increment and cost saving, input usage cost etc. These measures are based on various estimates obtained from the stochastic frontier analysis (SFA) and the observed data. Hence, the study applied statistical software SPSS 18 (Statistical Software for Social Science) in collaboration with Microsoft Excel 2010.

8.3 Addressing the Objectives

8.3.1 Estimates of productive efficiencies and partial elasticities

(i) The case of technical efficiency

The stochastic production frontier models, estimated with SFA to get technical efficiency of paddy production with the two FCDM systems, have fitted well to the data, providing a considerable number of parameters with statistically significant estimates. Most importantly, the model diagnostic parameters, e.g., sigma squared (σ^2) and gamma (γ) are statistically highly significant ($p<0.01$), indicating justification for the incorporation of inefficiency models with the frontier econometric models. Outcomes from these two models have addressed the first part of the first objective.

The mean productive efficiency score for paddy production with the SRM system in beel Dakatia is 0.7808, with dispersion ranging from 0.4833 to 0.9593, whilst that score in beel Bhaina with the TRM system is 0.7685, with dispersion varying from 0.4784 to 0.9801. The standard deviation of the scores in beel Dakatia and beel Bhaina are very close to each other at 0.1057 and 0.1167 points respectively. Furthermore, distributional patterns of the scores are also similar to each other. This was revealed by the coefficients of skewness and kurtosis. The coefficients of skewness for technical efficiency scores against SRM and TRM systems are respectively -0.508 and -0.193, indicating the distribution of technical efficiency scores is left skewed with each of management system; more specifically, the distribution under SRM is moderately skewed, while that under TRM is approximately symmetric. The coefficients of kurtosis of the efficiency scores are -0.418 and -0.681 for SRM and TRM respectively, showing that both of the distributions are mesokurtic.

Study results have shown that a higher percentage of farms with the SRM system belong to the upper ranges of efficiency scores, compared to the TRM system. For example, 49.27% of farms with the SRM system have an efficiency score of 0.80 and above, whereas only 41.45% of farms with the TRM system fall into this category. A contrasting picture is seen against the efficiency range below 0.60, where SRM's share is 4.39% but TRM's share is 9.21%; while against the middle range, the percentages of farms are almost the same for both of the systems; 46.34% and 49.34% for SRM and TRM respectively, making a difference of 3% only.

In terms of partial elasticity of output, the input variables appeared with dissimilar coefficients, a priori, indicating contrasting production environments under the two management systems. In the SRM system, 'TSP fertilizer' has appeared as the major dominant in paddy production with an average output elasticity of 0.209, followed by ‘seed’ at 0.146, ‘labour’ at 0.139, land preparation at 0.009 and irrigation at 0.007. Corresponding to the maximum likelihood (ML) estimates, the ordinary least square (OLS) estimates are 0.220, 0.136, 0.125, 0.004 and 0.016, in order. The first three of these estimates are statistically significant. Meanwhile, among the ML estimates in the TRM system, labour has emerged as the most influential factor with an average output elasticity of 0.242, followed by urea fertilizer at 0.215, irrigation at 0.118, dewatering at 0.084 and land preparation at 0.024; the corresponding OLS estimates of these variables are respectively 0.262, 0.197, 0.081, 0.055, -0.013 and 0.005, in order. It is noteworthy that the coefficients of urea fertilizer in the SRM system and TSP fertilizer in the TRM system are negative, indicating a variation in soil content between the management systems. Interestingly, these coefficients are almost the same; the coefficient for urea is -0.044 and that for TSP is -0.045; however, the latter is statistically highly significant. Dewatering is an important environmental factor having a negative coefficient of -0.110 with SRM system, unlike that with TRM system at 0.084; nonetheless, in both of the cases, the coefficients are highly significant ($p<0.01$).

In this analysis, soil quality is considered as an important environmental factor, assuming that it shapes the production environment to a large extent. Accordingly, soil dummies are supposed to be crucial determinants of output as far as paddy production is concerned. The coefficients of dummies for peaty soil and clay soil with the SRM system are -0.126 and -0.069 respectively, and their corresponding OLS coefficients are 0.117 and -0.048. Both of these estimates are statistically significant; these results indicate that a mixture of these two types of soil i.e., peaty-clay soil, is favourable for paddy production with the SRM system. Meanwhile, with the TRM system, the coefficient of the sandy-loamy soil dummy is -0.156, and that for clay-loamy is 0.047, having corresponding OLS estimates of -0.136 and 0.065 respectively.

On the other hand, returns to scale (RTS) of paddy production with respect to maximum likelihood (ML) estimates are 0.362 and 0.647 for the SRM and TRM systems respectively, while for OLS estimates these are 0.345 and 0.584. Returns to scale (RTS) for both types of estimates are significantly higher for the TRM system than for the SRM, which indicates that the output increment under TRM is costlier than that for SRM. In other words, TRM appears to be a more promising flood control and drainage management (FCDM) system. In the case of inefficiency model, the variables ‘experience’ and ‘ownership dummy’ with the SRM system have negative coefficients, while this is the case for only ‘age’ with the TRM system, implying that these variables contribute towards reducing inefficiency in paddy production. The rest of the inefficiency variables have positive coefficients with both of the management systems.

(ii) The case of cost efficiency

Cost efficiencies for fisheries production with SRM and TRM systems were obtained by estimating the stochastic cost frontier models with SFA. Results have shown that the econometric models for both of the systems fit very well with the data, providing most of the parameters with statistically significant estimates. The two model diagnostic parameters, sigma squared (σ^2) and gamma (γ), are, however, statistically significant at the 1% level. Significant estimates of model diagnostic parameters have indicated that there exist inefficiency effects in fisheries production, justifying the inclusion of the inefficiency effect model with the stochastic cost frontier model. Cost efficiency and relevant estimates satisfy the second part of the first objective.

The mean cost efficiency scores of the farms with SRM and TRM are 0.807 and 0.762 respectively. The efficiency scores in the SRM system are spread widely, ranging from 0.263 to 0.953 with a standard deviation of 0.275; in contrast, the range of scores with TRM is narrower, varying from 0.426 to 0.950 with a smaller standard deviation of 0.128. Distributional patterns of these scores vary noticeably, unlike the patterns found in the technical efficiency scores. The coefficient of skewness for cost efficiency scores for SRM and TRM systems are -1.728 and -0.752 respectively, which indicates that cost efficiency scores with SRM are highly skewed, while those with the TRM system are moderately skewed. The coefficients of kurtosis, another measure of distributional patterns, with the SRM and TRM systems are respectively 4.154 and -0.413, indicating that efficiency ratings with SRM are leptokurtic, whereas they are platykurtic with the TRM system. Meanwhile, the proportional distribution of the farms, in terms of the percentage share by efficiency ratings, shows that more than 62

% of farms with SRM have cost efficiency scores of no less than 0.80, whereas only 50 % of farms with TRM qualify for this category. The percentage of TRM farms against the middle (0.60 to >0.80) and lowest (below 0.60) range are respectively 35.52% and 14.48%, and these percentage shares are more than their corresponding shares with the SRM system by 4.79% and 7.65% respectively.

In the case of cost frontiers, variables have contributed to the total cost to varying extents for both of the management systems. Cost elasticity of the total output with the SRM system is 0.588 and 0.419 with the TRM system; both of these estimates are statistically highly significant ($p<0.01$). Corresponding OLS estimates of cost elasticity for 'total output' with SRM and TRM systems are 0.486 and 0.454 respectively. The most contributing factor to cost with the SRM system is 'feed price', having a coefficient of 0.494, followed by 'fingerling price' at 0.444, 'gher preparation cost' at 0.188 and 'disease control cost' at 0.065. Meanwhile, with the TRM system, the fingerling price appears to be the second most contributing factor to the cost of fisheries production, with a coefficient of 0.380, followed by 'disease control cost' at 0.101, 'gher preparation cost' at 0.081, and 'feed price' at 0.060. All of these estimates are statistically significant except feed price with the TRM system. The corresponding OLS estimates of these factors are 0.473, 0.356, 0.219 and 0.091 for the SRM system, and 0.423, 0.112, 0.115 and 0.115 for the TRM system, in order.

With regard to the inefficiency variables, the 'extension dummy' has appeared with a negative coefficient for each of production environments and the estimates are statistically significant, whilst the rest of the inefficiency variables have positive coefficients with SRM system and negative estimates with TRM system.

8.3.2 Yardsticks of Productivity: Yield-gap and cost-gap along with PYI and PCS

The second and third objectives of this study have been met through addressing research questions (C) and (D), using standardized formulae that dealt with yield-gap and cost-gap primarily. Measurement of these two types of gaps (i.e., yield-gap and cost-gap) are widely used in the literature of performance evaluation. However, it has been observed that under the SRM and TRM production environments, the yield-gaps are respectively 719.181 (kg) and 807.324 (kg), whilst cost-gaps are tk. 12542.713 and tk. 14440.386 per acre of land. It is noteworthy that yield-gap applies to paddy production and cost-gap to fisheries production in this work. A useful statistic here is the ratio of corresponding gaps; this ratio can provide an idea at a glance about the size of the gaps under consideration. For example, the ratio of the yield-gap with SRM to that with TRM for paddy production has been found to be 1.23, while the ratio of cost-gaps with SRM to TRM against fisheries production has been recorded at 1.15. Both of these ratios indicate that the difference between the gaps is not large. Meanwhile, the average ratings of potential yield increments (PYI) for paddy production have been found to be 30.532 and 33.371 for SRM and TRM systems respectively. For a thorough understanding, these ratings have been broken down for different farm groups. It has been observed that for the SRM system, potential yield increment ratings are 62.550, 26.481 and 9.570 against the bottom (lowest), middle and top (upper) 20% farm groups respectively; meanwhile, these ratings are 68.280, 29.624 and 7.800 for the TRM system in order. In the case of fisheries production, the ratings of potential cost saving (PCS) with the SRM and TRM systems, on average, are 19.325 and 23.783 respectively. Furthermore, these ratings for the lowest, middle and upper 20% farm groups, are respectively 37.931, 17.083 and 7.198 with the SRM system; and 44.75, 20.462 and 9.590 with the TRM system in order.

Table 8.1: Technical and cost efficiency scores with the FCDM systems at a glance

Particulars	Technical efficiency		Cost efficiency	
	SRM (beel Dakatia)	TRM (beel Bhaina)	SRM (beel Dakatia)	TRM (beel Bhaina)
Mean	0.782	0.769	0.807	0.762
Maximum	0.959	0.980	0.953	0.950
Minimum	0.483	0.478	0.263	0.426
Std. Deviation	0.106	0.117	0.275	0.128

Source: Extracted from tables 5.6 and 6.6

8.3.3 Input usage costs with paddy production

The cost of production per quintal of paddy with SRM system is less than that with TRM, on average (for the all-farm group). These costs are tk. 735.06 and tk. 854.76 for SRM and TRM respectively. The upper 20% farm group records relatively smaller costs per quintal of paddy production and these are tk. 585.94 and tk. 703.49 with SRM and TRM systems. Meanwhile, on average, the total cost of inputs applied per acre of land in producing paddy by the farms belonging to SRM system are tk. 19629.27, whereas that cost for TRM is tk. 22717.53. Similar cost figures are found for the upper 20% farm group, with tk. 20349.44 and tk. 22493.20 for the SRM and TRM systems respectively. However, in both of the cases, the margins are not wide.

8.4 Policy Recommendations

Findings for performance evaluation of the SRM and TRM systems in terms of agricultural productivity reveal that SRM performs relatively better than TRM, although the margin is narrow. Thus, from a short/medium term policy perspective, the SRM system should get priority over TRM. However, consideration of other aspects of these two systems may necessitate a re-examination of this conclusion. For example, if operational costs, as well as the long term impact of these systems, are taken into consideration, the scenario may be different. Therefore, further study of these systems and their long term impact assessment are necessary before making a final judgment. To this end, important aspects and/or realities worthy of consideration include 'costs involved in delivering the a management system', 'salinity control and ground water level', 'coping with relative sea-level rise' and 'overall management mechanisms', since these are the crucial factors that determine the success of a flood control and drainage management system in a coastal zone.

8.4.1 Maintenance of SRM and TRM systems

(i) Internal drainage network maintenance

There is a big difference between SRM and TRM systems in terms of their maintenance costs. In the case of an SRM system, a large amount of costs is required for maintaining internal drainage canals and passages, apart from routine maintenance of regulators. The success of an SRM system largely depends on internal drainage management. Due to internal drainage congestion, farmers require to pumping out excess water from their farm lands before paddy cultivation. Study results show that cost of dewatering with SRM is significantly higher than that with TRM. Farmers with SRM system require on average, 33.39 litres of diesel (costing about tk. 2099.23) to pump out excess water from their paddy fields while farmers with TRM system require only 10.31 litres for the same purpose. Focus group discussion (see Appendix 4) reveals that lack of proper maintenance of the internal drainage system is one of the causes of a higher cost of dewatering. So, proper maintenance of internal drainage network systems would help minimize the cost of dewatering as well as the cost of production. In fact, internal drainage management is one of the important factors that determine the success of SRM system (Uddin and Yasmin, 2005).

(ii) Soil productivity improvement

The study results reveal that quality of soil contributes significantly to the level of productivity with regard to growing paddy. Mixed soils are more favourable for paddy production. The coefficients of individual dummies for peaty and clay soils are respectively -0.3.95 and -0.1.75 in beel Dakatia and these are statistically significant. In beel Bhaina the coefficients of dummies for sandy-loamy and clay loamy soils are -0.3.34 and 0.047; but the latter is not statistically significant. These results indicate that mixed soils i.e., the peaty-clay soil in beel Dakatia and sandy-clay-loamy soil in beel Bhaina positively contribute to paddy production. However, there remains scope with both of the management systems to improve soil quality by bringing a balance in nutrient contents, which in turn would contribute to higher productivity. In passing, the original soil in the study area was peaty since the area was a part of the Sundarbans once upon a time (Uddin and Yasmin, 2005, p. 19). Over the passes of time, this area had gone through different hydrological regimes that cause to change soil to take different qualities in terms of nutrient contents.

In the case of the TRM system, a peaty soil layer no longer remains as top soil, because of sediment deposition on it through tidal inundation; hence, measures can be taken so that the top soil gets mixed up with the peaty soil. This mixed soil would become rich in nutrient contents and contribute to agricultural productivity. According to the soil test report of the EIA/SIA study of CEGIS, the sediments of the Hari River contain calcium, copper, magnesium, manganese and sulphur (CEGIS 1998, p. 106). However, in the case of TRM, blending can be made easily given how gher farming is practiced. When the canal and the tub in a gher are excavated, the peaty spoils to be spread over the agricultural land instead of using it for building the dykes. Contrary to the TRM system, the top soil in the SRM system is predominantly made up of peaty soil; hence, the dredged spoil to be spread on the gher land.

8.4.2 Control over salinity and groundwater level

Salinity problem and falling of groundwater level are very important issues for both SRM and TRM systems and often these two problems are interrelated. The reasons behind salinity problem with the SRM and TRM systems are similar for the most part. For a TRM system, there are two main sources/factors that can affect the salinity in the operated area. Firstly, through the seepage of saline water from nearby tidal flow; and secondly, from the diverted tides into the area. The first scenario can be prevented in two ways: i) ensuring enough freshwater flows from upstream through the nearby tidal channels and rivers; ii) preserving the underground water at such a level that it prevents seepage of outside saline water and this can be ensured by controlled ground water abstraction for irrigation. Hence, farmers should be encouraged to use surface water for irrigation. Indeed, surface water irrigation has a number of advantages over ground water (Stigter et al., 2006). Farmers can have easy access to surface water by preserving rain water in the canal inside the gher. For this purpose, canals inside a gher need to be made wider so that they can contain enough water even in the dry season. This practice also applies to SRM system in beel Dakatia. A focus group discussion on the Dakatia beel revealed that in some areas, the groundwater level has fallen, requiring deep boring for abstraction of ground water for irrigation. So in an SRM system, irrigation from surface water also needs to be encouraged. Hence, gher canals, as well as beel canals, can be used as the main sources of surface water.

The second way that causes salinity problem is the flow of tides with saline water diverted to the TRM beels/project area. Focus group discussions revealed that in beel Bhaina some unscrupulous fish farmers illegally divert saline tides into their ghers for culturing brackish water shrimp. Brackish water affects paddy farming as the salinity level of the soil increases. A handful of big fish farmers are the beneficiaries of unlawful intrusion of saline water in the project area, while the vast majority of the farmers are the sufferers (Uddin and Yasmin 2005; Tutu et al., 2009, p. 9). Increased salinity negatively affects seed germination (Katembe et al., 1998; Ungar, 1996) that entails more use of seed than the usual requirement per unit of land. Farmers in beel Bhaina apply extra doses of fertilizers and other materials to reduce the adverse effects of salt in the soil. Summary statistics (table 5.1) shows that average cost of (paddy) seed per acre with TRM is significantly higher than that with SRM by a margin of by tk. 158.90. Meanwhile, the amount of urea fertilizer used per acre of paddy farm with TRM is also significantly higher than that with SRM and the difference here is more than 45 kg on average. It is to be mentioned that saline-free soil is not the only reason here for less use of urea with SRM system; the peaty soil which contains substitutes of urea fertilizer is also attributed to this cause. However, illegal intrusion of saline water by influential shrimp farmers is also practiced in other parts of Southwest coastal zone of Bangladesh where paddy production have drastically fallen (e.g., Khalsi village in Dakop upazila in Khulna, as reported by Roy, 2008); at the same time, there are areas that are no longer affected by saline water and harvesting bumper crops (e.g., Bazua area just 3-kilometers down from Khalsi) (see Roy, 2008).

Further, the author reported that paddy production in a saline-free area is significantly higher than that in a saline affected area.

On the other hand, study results have shown that the SRM system performs relatively better with both paddy and fisheries production. In the SRM system, freshwater prawn and carp fisheries are cultured, whereas, in the TRM system, brackish water shrimp is cultured along with those two varieties. Hence, it can be contended if brackish water had not been taken into the TRM protected area, the overall performance of the TRM system in agricultural production would not fall. Therefore, rules and regulation need to be enforced in this regard, so that none can dare to enter brackish water into TRM operated areas. It is noteworthy here that that the cultivation of Bagda alone is more environmentally damaging than the cultivation of freshwater golda and paddy or another crop (CEGIS 2001, p. 24).

8.4.3 Counteracting the rise of relative sea-level

The rise of relative sea-level is an undeniable fact and the low-lying coasts bear the brunt of its impact. Global warming and land subsidence are the two most responsible factors behind the rise of relative sea-level. Global warming is caused primarily by the emission of greenhouse gases (GHG) and coastal land subsides (sinks) for a number of reasons e.g., crustal deformation under the weight of deltaic sediments, erosion, drying and compaction of sediment etc. However, along with controlling the above factors it would be wise to adopt measures that would counteract the rise of relative sea-level. Hence, any intervention in the coastal areas to be designed in such a way that it is responsive to land subsidence and sea-level rise, i.e., the rise of relative sea-level, and at the same time, no intervention should be allowed/chosen that aggravates the situation.

The rise of relative sea-level refers to the combined effects of a global rise in sea-level and the sinking of the land surface. That relative sea-level is rising is a proven fact, although different studies have come up with contradictory rising rates with reference to the context of the Southwest coastal zone of Bangladesh (see Syvitski et al., 2009; Hanebuth et al., 2013; Brammer, 2014). However, it is obvious that relative sea-level is rising and the rate is not negligible. In these circumstances, it would be pragmatic to undertake mitigating measures before the situation deteriorates further and go beyond control. Of the two FCDM systems, TRM counteracts the rise of relative sea-level through its normal course of action; whereas SRM further aggravates the situation. In the TRM system, floodplains, tidal mud flats or beels become elevated by vertical accretion of sediments; in contrast, in the SRM system, the land level is further decreased by erosion, making it more vulnerable to sea-level rise. Thus, it is the TRM system that can provide sustainable agriculture as far as tidal mudflat floodplains are concerned. However, considering overall situation it can be contended that as an FCDM system TRM has the upper hand on SRM.

On the other hand, perhaps there is no other safe and cost effective way to raise the bed inside the SRM system other than to use decaying vegetation. As far as SRM is concerned, the decay of vegetation is a small step and very slow process of elevating the land; as a result, it would take an extensive period of time to capitalize on a sizable amount of land elevation. Indeed, it is not an effective way to cope with the rise of relative sea-level at the present time. However, it would not be wise to stop this process as small improvements are better than none. Hence, encouragement, as well as awareness building initiatives are important so that farmers leave residues/trunks of crops on the farm lands and do not burn or remove them.

8.4.4 Issues relating to overall management

(i) Restoration of wetland biodiversity

Focus group discussions have informed that biodiversity has been affected more or less under both of the FCDM systems. However, a decline of biodiversity under SRM system is more widespread than that under TRM, since SRM system functions contrary to the natural setup. These two systems are basically parts of systematic interventions for reclaiming low-elevation coastal land for agriculture. The SRM, in particular, is a successive phase of reclaiming low-lying land which was started in 1960s. Prior to the 1960s, these areas would be inundated with the tidal flow (CEGIS 1998, p. 10), and there were perennial water bodies; thus biodiversity of the area would be maintained. Most of the coastal floodplains contain some forms of perennial or semi-perennial water bodies that support the related biodiversity. Once a floodplain is brought under TRM operation, the water body associated with it would be filled up or deformed unless special arrangements are not taken up.

However, it is highly recommended that with each management system (i.e., in each beel) at least one patch of land (preferably the lowest-elevation part) be delineated/designated as ‘protected wetland’ to restore and/or sustain biodiversity of the area. The bigger the size, the better; however, the size should not be less than one-tenth of the whole beel. A wetlands can benefit agriculture in many ways e.g., by reducing the use of pesticides in crop production, since it works as a habitat of the main predators (e.g., birds, different species of amphibians etc.) of cropland insects; extending surface water irrigation facilities; maintaining underground water level through recharging aquifers and so on. Focus group discussions reveal that a wetland has other socio-economic implications as well; for example, poor people can sustain their livelihoods from the diverse resources of a wetland at least partially.

(ii) Open water fisheries management

Like wetland preservation, promoting open-water fisheries have significant socio-economic implications, in addition to protecting biodiversity. It provides employment opportunities for the local people and it is a rich source of protein. Focus group discussions reveal that both of the FCDM systems more or less affect open-water fisheries; where there is a regulator; there is a restriction on movement and migration of open-water fisheries (CEGIS, 1998, p.73). Regulators disconnect and/or reduce habitats for open-water fisheries in many ways: controlling free movements of fisheries, reducing the length of the migration route, preventing the exchange of water qualities, providing inadequate water levels and so on. These obstacles in turn adversely affect breeding and spawning conditions for open-water fisheries. The higher the number of regulators, the greater is the adverse impact on open-water fisheries. So, the negative impact of SRM system on open-water fisheries is remarkably higher than that of the TRM system. Contrarily, in some instances, TRM favours open-water fisheries as far as open-water capture fisheries are concerned. It is evident from TRM operations in beel Bhaina and beel Khuksia that TRM does not affect open-water fisheries per se. Referring to the local people, CEGIS (2001, p. 22) reported that ‘there was a tremendous rise in open-water capture fisheries’ during the first and second year of TRM operation in beel Bhaina. In the case of TRM operation in beel Khuksia, a lot of open-water fisheries had been captured every year, as witnessed by the author during fieldwork. FGDs also revealed the same information. It is widely believed that these captured fisheries can compensate for a considerable share of crop losses during TRM operation. Hence, what is needed is a systematic and effective control mechanism in order to capitalize on the full benefit from capture fisheries.

However, there are some measures that can reduce the adverse impact on open-water fisheries due to the SRM system. The first and most important measure is to keep the number of regulators as low as possible. In addition, regulators should be designed in such a way that they facilitate free movement of fisheries. For example, additional gates with two directional flow provisions or separate fish pass structures can be built alongside the regulators. Most importantly, special care should be taken during peak migration periods and the whole process needs to be monitored /supervised by a team of experts in relevant fields. Furthermore, fish fingerlings can be released annually into different fish habitats that have been delinked from fish migration routes (CEGIS, 1998, p. 105). Supervision and monitoring of the peak migration period of fisheries and release of fish fingerlings need a coordinated effort. Hence, the involvement of relevant institutional bodies and individuals (e.g., local government administrations, fisheries department, peoples' representatives in local government organizations, and Non-government Organizations (NGOs) and above all, local elites) would make the effort more effective.

8.5 Contribution to Production of Knowledge

The present research work contributes to the existing knowledge in the broader area of water resources and flood management in several distinctive ways. Firstly, this study addresses a gap in the relevant literature: flood control and drainage (FCDM) systems are usually evaluated from engineering perspectives i.e., in terms of flood protection potential and/or risk assessment; while this study evaluates FCDM systems from productivity perspectives, which is the first of its kind in the literature of water resources and flood management, to the best of our knowledge. In addition, by addressing the gap in the literature, this study also contributes to the methodology of performance evaluation: the stochastic frontier analysis (SFA) had been applied to different sectors and sub-sectors (e.g., irrigation projects, credit programmes, quota systems and so on) for performance evaluation; but SFA had not been used to evaluate performance evaluation in the area of flooding management, let alone, the area of flood control and drainage management.

Phillips and Pugh (1994) (cited in Hart, 1998, p. 24) identified nine definitions or points referring to the originality of a research work as well as the contribution to existing knowledge. The present study, fully complies with at least four of these definitions/points. One of the powerful definitions of originality, as given by Phillips and Pugh (1994),

(i)'. . . adding to knowledge in a way that has not previously been done before'

fits well the present study. Actually, this study makes a comparison between a unique and environmentally friendly flood control and drainage management (FCDM) system, the Tidal River-basin Management (TRM), and a typical technology-fixed hard engineering system thereby contributing to enhancing existing knowledge of water resource and flood management. There is no evidence of comparative study of the TRM system in the literature. Most importantly, the TRM approach addresses two environmental hazards– flooding and waterlogging– in tandem. Indeed, this work has contributed a new concept to the existing knowledge that would help further our understanding of the world in which we live.

Furthermore, the study area itself is unique in terms of its topographic and environmental features. There have been few or no studies of this kind in such a topographic and environmental setup. Thus, this work has satisfied at least three of the standards of originality, identified by Phillips and Pugh (1994). In their words, originality can be defined as

(ii). '. . .*doing empirically based work that has not been done before'*;
(iii). '. . . looking at areas that people in the discipline have not looked at before' and
(iv). '. . . applying a technique usually associated with one area to another'.

This study, indeed, has fulfilled these originality criteria (see Hart, 1998, p. 24).

In the agricultural sector, the evaluation of management systems or technological interventions has been performed involving many crop production environments including paddy, wheat, and dairy products, but little or no evaluation works have been carried out based on fisheries production, particularly the production environments where different species are grown at the same farm simultaneously.

8.6 Limitations of the Study

Empirical research works invariably suffer from different types of limitations. The present work is no exception to this. This research work has several limitations. The first limitation of this study involves the functional form of the econometric models used in data analysis. Of the two most commonly used functional forms in frontier analysis – Cobb-Douglas and translog – the latter is more flexible. However, despite some limitations of the Cobb-Douglas functional form, this study has used the estimates obtained from the Cobb-Douglas functional form. This is because of a considerable number of zero observations in the data set. If a translog functional form had been adopted to this analysis, it could generate too many zero observations through interactions among the variables, which in turn would raise another question of appropriateness for using translog functional form. In fact, the Cobb-Douglas model in this analysis produced more accurate and balanced estimates.

The second limitation of the present study relates to the non-negative and one-sided error term. Distributional specification of the one-sided error is an important issue concerning the analysis of stochastic frontier models. There are four types of distributional specifications that a non-negative error term can assume. However, the present study has considered only two of them, the half-normal and truncated normal distributions. Indeed, these two distributions are the most commonly used specifications in empirical studies involving frontier analysis.

When polishing the data, some of the surveyed questionnaires seemed to have aberrant data. In order to verify these data, it was necessary to contact relevant interviewees directly. This was a time-consuming and costly task once the researcher was away from the study area. However, due to time constraints, the identified interviewees were contacted over phone, but it was not possible to contact all of the identified interviewees because the farmers were busy at that time. So, a number of data sheets (survey questionnaires) had to reject; as a result, the total number of sample observations dropped from 380 to 357.

8.7 Conclusions

This study was undertaken with a view to addressing the gap in the literature through evaluation of two competing flood control and drainage management (FCDM) systems—the Silt-dredging and Regulative-drainage management (SRM) and the Tidal River-basin Management (TRM)—in terms of their performance in agricultural productivity within the production environment they bring forth. The TRM system manages flooding and waterlogging problems in line with the natural setup; while, SRM does it in a conventional way where hard engineering structures are involved (Tutu, 2005). Evaluation of these FCDM systems has been performed by addressing several research questions primarily related to productive efficiencies, more specifically, technical efficiency for paddy production, which complies with Zellner et al., (1966)'s assumption of expected profit maximization, and cost efficiency for fisheries production in accordance with the framework of cost minimization in the production process. In addition, there were research questions that sought to measure yardsticks of productivity in terms of yield gap, cost gap, potential yield increment, potential cost saving and level of input usage cost. However, estimates of productive efficiencies have been attained through analysing econometric models with stochastic frontier analysis; meanwhile, standard formulae and statistical methods were engaged to obtain yardsticks of productivity.

Outcomes of this study are produced in several ways for perceiving the reality. The percentage shares and/or frequency distributions of farms against efficiency scores have been used in many studies as reliable criteria for judging competing management systems(see, Bravo-Ureta and Pinheiro, 1997; Dawson et al., 1991; Dawson, 1990 and 1987b; Kumbhakar and Hesmati, 1995; Heshmati and Kumbhakar, 1997; Kalirajan, 1990; Karagiannis and Sarris, 2005). The present study, however, found that larger percentages of farms with the SRM system achieved higher levels of efficiency scores than the farms with TRM for both of the crops. Distributional patterns of productive efficiency scores, in terms of coefficients of skewness, echo similar outcomes. With SRM, the technical efficiency scores are moderately skewed; while they are approximately symmetric with TRM system. Again the mean technical efficiency score of the farms with the SRM system is higher than that with TRM; thus, it can be deduced that the SRM system is more efficient than TRM in paddy production. The distributional pattern of cost efficiency scores is also left skewed, in common with the technical efficiency scores with both of the management systems. But a highly skewed shape has been found for the SRM system, while it is moderately skewed for TRM; moreover, the mean cost efficiency for the SRM system is higher than that with TRM, meaning SRM system is more efficient than TRM in fisheries production as well. That means, for both of the crops SRM outperforms TRM.

In terms returns to scale (RTS), it is seen that each of the management systems operates under decreasing returns to scale. However, RTS with TRM is significantly higher than that with SRM. In other words, a one percent increase in all inputs would result in an output increment which is bigger with TRM than that with SRM. Contrary to the above findings, this observation has established the TRM system is more promising than the SRM, as far as paddy production is concerned. Meanwhile, the coefficient of cost elasticity for 'total output' with the SRM system is noticeably higher than that with TRM, meaning a one percent increase in total output would result in relatively higher cost with SRM than that with TRM. This finding is congruent with the findings for paddy production, re-establishing the result that the TRM system is more promising than the SRM, for fisheries production as well.

On the other hand, the measure of average yield-gap for farms with the TRM system appears to be higher than those with SRM, indicating a lower level of performance for farms with TRM in paddy production. In the case of cost gap, the status of the management systems in terms of performance remains the same, as the average measure of cost-gap is relatively higher for TRM farms. However, both yield-gap ratio and cost-gap ratio fall into the second category, (as mentioned in section 7.2.3 of chapter 7) termed Little Difference (LD), meaning the difference between SRM and

TRM systems in terms of yield-gap and cost-gap is very small. From these findings, it is clear that there exist differences between the SRM and TRM systems with respect to performance levels in paddy and fisheries production, but the extent of these differences is small.

Potential yield increment and cost saving also help to take a decisive conclusion (Bravo-Ureta and Reiger, 1991). Potential yield increment against two of the three farm groups is less with the SRM system than that with the TRM, attributing again more weight to the SRM system. Meanwhile, on average (i.e. for the all-farm category) the potential yield increment with SRM is also less than that with TRM. In the case of potential cost saving, the SRM system has shown better performance. Hence, measures of potential cost savings with the SRM system are significantly less than that with the TRM system on average (i.e., overall) and for each of the farm groups. Based on these findings, it can be deduced that SRM is a better performing system compared to TRM; however, in most cases, the margins are narrow again. Meanwhile, the total cost of inputs for producing per unit of paddy with the SRM system is less than that with TRM on average, which again confirms that the SRM system is better than the TRM as far as paddy production is concerned. Here the margin is not small but moderate.

Productive efficiencies are estimated using a stochastic frontier model with inefficiency effects by choice and not with a stochastic error component model. The error component model ignores the inefficiency effects of farm-specific and management variables and is unable to provide the overall efficiency estimate. However, the study assumed the truncated-normal distribution for the inefficiency effects, fit the stochastic model in the Cobb-Douglas functional form and analysed the model with the maximum likelihood method; while a single-stage procedure was followed for the estimation of the inefficiency effect model.

The SRM appears to be a more efficient system than the TRM in most of the cases, whilst in a few cases the TRM system has overshadowed SRM; however, the margin of difference between these two competing systems is not big in any occasion.

Considering the assessments with respect to productivity, it can be concluded that the SRM system is more favourable to agriculture than its counterpart, TRM.

In passing, if FGD report is taken into account, the above conclusion no longer exists. In terms of counteractive measures to the rise of relative sea-level, the TRM system overwhelmingly outperforms the SRM system. In fact, counteraction to the rise of relative sea-level with TRM through land elevation is an undeniable fact; it is indeed, a self-evident phenomenon. Furthermore, the SRM appears to be more expensive to deliver, as well as the fact that due to the rise of relative sea-level with the SRM system, it is likely to become increasingly expensive in the future. Therefore, if the overall evaluation is taken into consideration (including FGDs) the TRM system gains the upper hand as far as sustainable agriculture is concerned.

In sum, SRM system outperforms TRM system marginally in the short run; whilst, TRM outperforms SRM overwhelmingly in the long run.

8.8 Recommendations for Future Research

This work has analysed a number of important issues relating to the performance evaluation of flood control and drainage management (FCDM) systems and drawn a conclusion based on the results obtained. However, there remain a number of issues that could have been addressed in connection with the present research. In reality, it is not possible to address all relevant aspects of a research topic, since the body of knowledge in a discipline at the cutting-edge of science and technology is inexhaustible. However, the following issues in the broader field of performance evaluation involving FCDM systems are identified that require further research. This would enhance understanding the management systems and then provide more realistic policy prescriptions.

This study used cross-sectional data for evaluating two competing FCDM systems. It would have been better if panel data had been engaged in this evaluation. The productivity of a farm in agriculture may differ at least to some extent from one year to another because of the variations in natural phenomena such as rainfall, temperature and so on. In panel data, these effects are captured over a period of time, which enables the analysis to offer more representative and unbiased estimates. Cornwell and Schmidt (2008, p. 723) point out, "…that panel data are useful because they allow weaker assumptions or greater precision under a given set of assumptions than would be possible with a single cross section".

A further study could be carried out using a hybrid of a stochastic frontier model with the non-neutral shifting of the average production function proposed by Huang and Liu (1994). Specification of this non-neutral inefficiency model is more complex than the conventional inefficiency model in that it involves more variables generated by the interaction between input variables and actual inefficiency variables. However, it is may be argued that the non-neutral inefficiency model would provide better understanding about the inefficiency effects.

Cost-benefit analysis (CBA) is a widely practiced approach evaluate public interventions in the forms of projects, policies, programmes, investments and so on by comparing the economic costs and benefits of the activities involved. Thus, a cost-benefit analysis could be applied to judge competing FCDM systems such as SRM and TRM. One of the main strengths of CBA is that it converts qualitative data into quantitative figures that ease the decision-making process for all concerned, including the stakeholders. Indeed, CBA has the power to minimize differences in opinion which often emerge before undertaking a project or investment decision. However, in the case of evaluating flood control and drainage management systems, a social cost-benefit analysis would be more appropriate than the traditional cost-benefit analysis.

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Appendices

Appendix 1

Essential Properties of a Cost Function

According to Coelli et al., (2005, p. 23) the following properties are essential for a cost function.

Non-negativity: this property indicates that costs can never be negative; it is a finite real number.

Non-decreasing in input prices or monotonicity: this property states that with the increase in input prices costs will increase, not decrease. Symbolically, say, $\mathbf{p}$ is the vector of input prices; now, if $\mathbf{p}^0 \geq \mathbf{p}^1$, then $c(\mathbf{p}^0, \mathbf{y}; \beta) \geq c(\mathbf{p}^1, \mathbf{y}; \beta)$. Monotonicity implies that if cost function is continuously differentiable, all marginal costs are non-negative.

Non-decreasing in outputs: this property is similar to the above one, just replaces input prices with output quantities. Say, $\mathbf{y}$ is the output vector; now, if $\mathbf{y}^0 \geq \mathbf{y}^1$, then $c(\mathbf{p}, \mathbf{y}^0; \beta) \geq c(\mathbf{p}, \mathbf{y}^1; \beta)$.

Linear homogeneity in input prices: this property implies that multiplication of all input prices by an amount, say λ, ($\lambda>0$) would raise the cost by λ-fold. Mathematically, $c(\lambda\mathbf{p}, \mathbf{y}; \beta) = \lambda\, c(\mathbf{p}, \mathbf{y}; \beta)$.

Concave in input prices: One of the implications of this property is that input demand functions will be downward sloping. Symbolically, say, $\mathbf{p}$ is the vector of input prices; and $\mathbf{p}^0 \geq \mathbf{p}^1$, then the linear combination of $\mathbf{p}^0$and $\mathbf{p}^1$ will generate an amount of cost that is no less than the cost generated by the same linear combination of $c(\mathbf{p}, \mathbf{y}^0; \beta)$ and $c(\mathbf{p}, \mathbf{y}^1; \beta)$. Mathematically, $c(\zeta\mathbf{p}^0 + (1-\zeta)\, \mathbf{p}^1, \mathbf{y}; \beta) \geq \zeta c(\mathbf{p}^0, \mathbf{y}; \beta) + (1-\zeta)c(\mathbf{p}^1, \mathbf{y}; \beta)$ (for all $0 \leq \zeta \leq 1$).

Appendix 2

Derivation of Estimators

The Ordinary Least Square (OLS) Method

In the OLS method, as the name indicates, the residual values (i.e., the deviations between the actual and estimated values) are minimised. The sample regression function is given by

$y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} \ldots\ldots\ldots + \beta_n x_{ni} + \xi_i$ $\quad$ $(i=1, 2, 3, \ldots\ n)$ $\quad$ (A 2.1)

Now $\sum \xi_i{}^2 = \sum (y_i - \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} \ldots\ldots\ldots + \beta_n x_{ni})^2$ $\quad$ (A2.2)

From the equation A2.2, it is clear that

$\sum \xi_i{}^2 = f(\beta_0,\ \beta_1, \beta_2 \ldots\ldots\ldots \beta_n)$

i.e., the sum of the squared residuals is some function of the estimators. Given the data set, different values of the parameters provide different ξ_i, and vice versa. The principle of the least square method gives us estimates of the parameters in such a manner that $\sum \xi_i^2$ is as small as possible. Hence, the estimation process involves differential calculus, where the first derivative is set to zero.

Appendix 3

Derivation of Estimators

The Maximum Likelihood (ML) Method

The method of maximum likelihood, as the name indicates, estimates unknown parameters in such a manner that the likelihood (probability) of selecting the given sample points is as high as possible. The fundamental idea behind the technique of ML estimation is to determine whether a given sample of observation is more likely to have been extracted from some distributions than from others. In fact, ML estimators provide indications of the properties of the true population. For example, if the mean of a sample of data is 10.57, with all other variables remaining the same, then it is more likely that the sample has been extracted from a distribution having a mean of μ =12, than from a distribution with a mean of μ =20. Thus, the ML estimate of an unknown parameter is such that this estimate maximises the likelihood (probability) of the randomly selected observations in the sample.

In the ML method, formation of the density function is essential from the outset because it underlies the likelihood function, which is the basis of estimating parameters (Green, 2008)

Consider the sample regression function in (A 2.1)

$$y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} ....+ \beta_n x_{ni} + \xi_i \qquad (i=1, 2, 3, ...\ n) \qquad \text{(A3.1)}$$

It is well known that in estimating the classical linear regression model by the ML method, it is vital to make an assumption regarding the distribution of the error term. Usually, the error term is assumed to be normally distributed. The other most common assumptions regarding the error terms are *(i)* Non-zero mean value of the error i.e., $E(\xi_i) = 0$

(ii) Homoscedasticity (equal variance) of the error i.e., $E(\xi_i^2) = \sigma^2$ (A3.2)

(iii) Errors are uncorrelated (no autocorrelation in them) i.e., $E(\xi_i \xi_j) = 0$ *for all* $i \neq j$.

A combination of all these assumptions is written as

$$\xi_i \sim iid\ N(0, \sigma^2) \tag{A3.3}$$

which implies that the error terms are normal random variables, independently and identically distributed with means of 0 and variances of σ^2. Based on these assumptions, the relationship between y_i and ξ_i in equation A2.1, is expressed as

$$y_i \sim iid\ N(\mathbf{x}_i'\beta, \sigma^2) \tag{A3.4}$$

which again shows that y_i are normally and independently distributed with mean = $\beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} .... + \beta_n x_{ni}$ and variance = σ^2

The joint probability density function of y_i ,($y_1, y_2, ..., y_n$) is revealed as a product of n individual density functions as

$$f(y_1, y_2, ..., y_n \mid \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} .... + \beta_n x_{ni}, \sigma^2)$$

$$= f(y_1 \mid \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} .... + \beta_n x_{ni}, \sigma^2)\, f(y_2 \mid \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} .... + \beta_n x_{ni}, \sigma^2)$$
$$...f(y_n \mid \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} .... + \beta_n x_{ni}, \sigma^2) \tag{A3.5}$$

Given the mean and variance, the density function of a normally distributed random variable (hence y_i) is

$$f(y_i) = \frac{1}{\sigma\sqrt{2\pi}} \,.\, exp \left[-\frac{(y_i - \beta_0 - \beta_1 x_{1i} - \cdots - \beta_n x_{ni})^2}{2\sigma^2} \right] \tag{A3.6}$$

Placing equation A3.6 into equation A3.5 for each y_i yields

$$f(y_1, y_2, \dots, y_n | \beta_0 + \beta_1 x_{1i} + \cdots + \beta_n x_{ni}, \sigma^2) = \frac{1}{\sigma^n(\sqrt{2\pi})^n} . exp \left[-\sum \frac{(y_i - \beta_0 - \beta_1 x_{1i} - \cdots - \beta_n x_{ni})^2}{2\sigma^2} \right]$$

(A3.7)

This joint density function (pdf) in equation A3.7 is known as *likelihood function* and is often denoted by {*L* (*random variable | parameters to be estimated)*}, as

$$L\ (y_i | \beta_0, \beta_1, \beta_2 \dots \beta_n, \sigma^2) = \frac{1}{\sigma^n(\sqrt{2\pi})^n} . exp \left[-\sum \frac{(y_i - \beta_0 - \beta_1 x_{1i} - \cdots - \beta_n x_{ni})^2}{2\sigma^2} \right]$$

(A3.8)

Hence, the likelihood function is L (y_i | $\beta_0, \beta_1, \beta_2 \dots\dots\dots \beta_n, \sigma^2$), which implies that the random variable y_i is known or given, but $\beta_0, \beta_1, \beta_2 \dots\dots\dots \beta_n$, σ^2 are unknown and to be estimated. This probability density function reveals the probability of the sample observations as a function of unknown parameters βs and σ^2. These estimators is obtained by maximising the joint probability density function with respect to the parameters, which is a straightforward exercise in differential calculus. For differentiation, it is convenient to express the function in logarithmic form as

$$\ln L\ (\beta_0, \beta_1, \beta_2 \dots \beta_n, \sigma^2) = -ln\ \sigma - \frac{n}{2} \ln(2\pi) - \left[\sum \frac{(y_i - \beta_0 - \beta_1 x_{1i} - \cdots - \beta_n x_{ni})^2}{2\sigma^2} \right]$$

$$or, \quad \ln L\ (\beta_0, \beta_1, \beta_2 \dots \beta_n, \sigma^2) = -\frac{n}{2} \ln(2\pi) - \frac{n}{2}\sigma^2 - \left[\sum \frac{(y_i - \beta_0 - \beta_1 x_{1i} - \cdots - \beta_n x_{ni})^2}{2\sigma^2} \right]$$

(A3.9)

The logarithmic form of the likelihood function is called the *log-likelihood function*, which is used for maximisation. This logarithmic transformation is monotonic and does not affect the outcome of maximisation because any parameter values that maximise the likelihood function also maximise the log-likelihood function (Coelli et al., 2005, p.217). In practice, the log-likelihood function is partially differentiated with respect to the parameters and set to zero; algebraic manipulation provides the maximum likelihood estimators[1].

[1]Maximisation with respect to βs is equivalent to minimising the sum of squares in the OLS method. With this in mind, it can be concluded that when errors in the classical linear regression are normally distributed, the ML estimators for βs are identical to the OLS estimators.

Appendix 4

Informal Focus Group Discussions

Research Topic: **Evaluating Flood Control and Drainage Management Systems from a Productive Efficiency Perspective: a Case Study of the Southwest Coastal Zone of Bangladesh**

Newcastle University, United Kingdom

Title of the FGD:

Report on TRM and SRM as safeguards for agriculture in the Southwest coastal zone of Bangladesh

Time: During the year 2011-12

Name of the Enumerators:

Coordinator: Mr. Darul Islam Khan

Assistants: Mr. Tanup Mandol
Mr. Biprodas
Mr. Sagor Hossain

Summary of the Project

A couple of informal focus group discussions were held at different times in the year 2011 for gathering information about two flood control and drainage management systems, the TRM and the SRM, and their impact on agriculture. These FGDs primarily involved the paddy and fisheries farmers and local government representatives (former and incumbent). Prior to these FGDs, a good number of informal meetings were held with local level water experts, educated farmers, water resources engineers and local elites, a wide range of issues relating to SRM and TRM systems including improvement of overall management and safe agriculture were discussed. Outcomes of these meetings as well as expert opinions were also discussed in the FGDs. Through these meetings and focus group discussions information were gathered for better understanding about the strengths and weaknesses of the management systems, possible scenario, farming practices and the necessary actions/measures towards safe agriculture. It became clear that flood risk is higher with SRM system although it involves relatively a higher cost for operation and maintenance. In contrast, flood risk is less with TRM and it has the potential for safer and sustainable agriculture.

The list of outcome

The discussions were designed to get information in regard to the following issues. The first three question deals with general information while the remaining three relate to policy issues.

1. *To understand the background of implementing the SRM and TRM as safeguards against flooding and waterlogging for protecting agriculture in the Southwest coastal zone of Bangladesh.*

2. *To understand the overall situation in the pre-intervention period, particularly the risks in agriculture and level of productivity.*

3. To understand the input requirements for paddy and fisheries and output levels with both of the FCDM systems.

4. To understand the effectiveness of the FCDM systems (the SRM and TRM) in terms of protection from flooding and waterlogging.

5. To understand the challenges of implementing the FCDM systems

6. To understand the challenges of maintaining productive environment under the FCDM systems

Summary of the findings (by question):

1. *To understand the background of implementing the SRM and TRM as safeguards against flooding and waterlogging for protecting agriculture in the Southwest coastal zone of Bangladesh.*

Waterlogging problems at different places of the Southwest coastal zone began to emerge in the early 1980s and the situation progressively worsened due to mismatched interventions. These interventions were designed following the basic principle of polder; however, local people protested against the interventions since they had bitter experience with polders. Eventually, the Silt-dredging and Regulative-drainage Management (SRM) and Tidal River-basin Management (TRM) systems were implemented.

2. *To understand the overall situation in the pre-intervention period, particularly the risks in agriculture and level of productivity.*

There was a high risk of flooding and waterlogging in the pre-intervention period which dates back to mid-1980s. Output level was low compared to present time. This is because of cultivation of the traditional variety of rice and inadequate application of chemical fertilizers. Moreover, there was a lack of agricultural extension service.

3. To understand the input requirements for paddy and fisheries and output levels with both the FCDM systems.

Usage of some of the inputs (e.g., urea, TSP, irrigation and dewatering) for paddy production significantly vary with the management systems. For example, relatively higher amounts of urea and irrigation are applied to paddy production with TRM system than SRM system. The reverse is true for the TSP and dewatering. On the other hand, feeds for fisheries differ with species. The brackish water shrimps mostly dependent on naturally grown feed in the gher; in contrast, the fresh water prawns depend on external feed. The brackish water shrimp variety is believed to be omnivorous and farmers require to supply less of feed to this variety compared to the fresh water prawn variety.

4. To understand the effectiveness of the FCDM systems (the SRM and TRM) in terms of protecting flooding and waterlogging.

Each of the systems has been protecting the agriculture of the respective areas for the last two decades. However, the TRM is a more effective in terms of flood risk management; actually, risks of flooding with SRM is higher compared to the risks with TRM system. It is to be mentioned here that high risk with SRM is partly due to poor maintenance of internal drainage system and unplanned construction of ghers. Meanwhile, TRM is more promising system in providing sustainable agriculture since this system elevates low-lying floodplains/beels through sediment accretion in an environmentally friendly way. As a matter of fact, the TRM system counteracts the rise of relative sea-level , whilst the SRM system acts in the reverse order (through erosion and land subsidence), making the area susceptible to sea-level rise.

5. To understand the challenges of implementing the FCDM systems

There are challenges involved in implementing and maintaining each of the FCDM systems. However, the common challenges involved when implementing a management system include land acquisition for perimeter embankments and their construction, excavation of the connecting canals, and initial dredging. Land acquisition for an SRM system is made for the long term, while that for a TRM system is for the short term (except for a fixed basin mode).

SRM is such a system that requires a number of regulators, which is a costly affair. Dredging is vital for this system and is required throughout the year which involves huge cost (e.g., equipment purchasing, fuel etc.), alongside operation and maintenance. Again, disposal of the dredge spoil not only involves cost but also inconveniences.

In contrast, TRM operation incurs additional costs only for building a cross dam on the river upstream in order to divert tidal flow to the intended floodplain/beel through the connecting canal(s). The overall operation cost for the TRM system is much less than that for the SRM system. However, there are some technical, institutional and social challenges regarding implementation of TRM, which include selection of appropriate tidal basin/beel, uneven sedimentation inside the beels (in case of open tidal flow inside the beel), local government issues, crop compensation and conflict between interest groups, in particular, between fishers and farmers.

6. To understand the challenges of maintaining productive environment under the FCDM systems

Under the SRM system, tides are restricted downstream and this has a number of adverse impacts on the environment. For example, brackish water creatures in the floodplain/beel no longer exist, which in turn affects bio-diversity and livelihoods of local people; ground water levels also sink further in upland areas, raising the cost of ground water irrigation; the flushing facility of monsoon tides no longer exists; as a result, water quality inside the SRM controlled area deteriorates, making the fisheries susceptible to disease. The flushing facility plays a very important role, since it can prevent the aforesaid problems; in fact, it can improve the overall situation inside the SRM system. In contrast, the TRM system is not usually subject to those problems since it experiences flushing naturally.

Open water fisheries are severely affected by SRM system because of regulators which restrict the movement, breeding environment of fisheries. The TRM system also affects the promotion of fisheries but not as such. In fact, there prevails a kind of natural environment for open water fisheries during the period of TRM operation. However, some promotional initiatives like releasing fish fingerlings and monitoring mechanism can subside/offset many of adverse impacts due to the FCDM systems.

Appendix 5
Questionnaires for Farm Household Survey

Research Topic: Evaluating Flood Control and Drainage Management Systems from a Productive Efficiency Perspective: a Case Study of the Southwest Coastal Zone of Bangladesh
Newcastle University, United Kingdom

Section1
General Information about the principal farm operator

1.1 Identification of the respondent

Sample no.
Name: .... Father's Name: ....
Village: .... Mauza: ....
Upazila: .... Phone: ....

Experience in *paddy* cultivation: ..... yrs Experience in fish farming: ..... yrs

1.2 Family labour statistics

Sl. no	Relationship to the farmer	Age	Education (years of schooling)	Occupation (code)	
				primary	Subsidiary
	Farmer himself				
1					
2					
3					

Note: The sons/daughters or brothers/sisters of the main farm operator are to be considered as contributing to the farm operators' family through labour.

Code 1: 1= Agriculture 2= Fish farming 3= Business 4= Service 5= Agricultural labour 6= Non-agricultural labour 7= Fishing 8= Others (please specify).

1.2 Total Land holdings and its features

Ownership type	Cultivable land (decimal)
own	
Leased in (*hari*)	
others	
Total Land	

Section 2
Information about paddy production

2.1 Particulars of the plot for paddy production inside a gher

i) Name of the plot or any identity: ....
ii) Size (decimal): ....
iii) Present value /rent (Tk.): ....
iv) Land area used for canal (decimal):

v) Land area used for peripheral embankment:

(Measurement in decimal)

Other Particulars	Different Features
vi) Type of ownership: own...............leased in	
vii) Soil type: loamy / peaty / sandy clay /other (specify)	
viii) Sources of Irrigation: pumping from the canal inside the gher........ pumping from the canal of the beel..................... underground .... other	
ix) Dewatering/ Drainage system: using pump.............. other............	

x) Is there any waterlogging for a period of around two weeks during monsoon season in the plot? Yes / No
If yes, how much water?

2.2 About the seeds

i) Quantity of seed used (kg):
ii) Price/ kg:
iii) Total cost:
iv) Source of seed: own / Govt. (BADC) / seed dealer / open market / other
v) Is there any special characteristic(s) of this variety of paddy? yes / no
If yes, please specify:
vi) Date of plantation: ....

vii) Date of harvest: ....

2.3 Input usage costs for paddy production

Cost items↓		Boro paddy		
		Quantity	Price/unit	Total cost
1.Raising of seedlings (bed preparation, boundary repairing and nursery raising) Total labour =				
2. Dewatering	diesel (litre)			
	pumping hrs.			
3. Tilling and levelling	tractor hrs.			
	local method			
4. Labour requirement for uprooting and transplantation				
5. Weeding	total labour:			
	medicine			
6. Manure				
7. Fertilizers (kg) a) urea ....times b) TSP ....times c) Potassium ....times d) Others (please specify)		....	....	
8. Irrigation	diesel (litre)			
	pumping hrs.			

9. Pest and disease control	cost of medicine			
	integrated pest management (IPM)			
10. Total labour for harvesting				
11. Total labour for application of different inputs				
12. Other costs				

2.4 Information regarding usages of important inputs (e.g., fertilizer, pest control and irrigation):

a) Do you know the appropriate dose of fertilizer? Yes / no
b) If yes, had you applied the appropriate dose? Yes / no
c) Do you have any knowledge of integrated Pest Management (IPM)?
if yes, have you applied IPM? yes / no

2.5 Annual yield from the plot and its market value
a)

Produce		Quantity	Market price
Borro paddy	paddy (kg)		
	straw (thousand)		

2.6 The nature and sources of technological knowledge and logistic support

a. Nature and extent of agricultural extension services
i) Do you maintain contact with the agricultural field supervisors? ....Yes| No.
If yes, then what is the frequency? ....days in 3-months
ii) Have you had any agricultural training? Yes/no.
If yes, what was the topic and length of the training programme/period? .... days

b. Have you taken any loan for agricultural activities? Yes/no
If yes, what are the sources of your loan?

Section 3
Information about fisheries production

3.1 Information about the fish pond (gher)
a) What was the average depth of water in the entire gher?
b) What was the depth of the canal with respect to paddy plot?
c) Is there any special feature of the gher? Yes / no
If yes, please describe
3.2 Information about the fry and fingerlings discharged at the gher
a) Cost of the fry and fingerlings

Bagda (Shrimp)			
Types	Total number (in thousand)	price/thousand	total cost
fry			
fingerlings			
Golda (prawn)			
fry			
fingerlings			
White fish			
fingerlings			

b) What are the sources of bagda fry and fingerlings?
Number of times discharged? .... times
Date of first discharge:

c) What are the sources of golda fry and fingerlings?
Number of times discharged? .... times
Date of first discharge:

3.3 Input usage costs for fisheries production by variety

Cost items↓		Bagda/ Golda/White-fish		
		Quantity	Price/unit	Total cost
1. Dewatering	diesel (litre)			
	pumping hrs.			
2. Labour requirement for earth cutting, canal digging boundary building, repairing and maintenance:				
3. Preparatory tilling	tractor hrs.			
	traditional method			
4. Watering (power pump/ rainfall)	diesel (litre)			
	pumping hrs.			
5. Application of different types of feeds, fertilizers and lime (during and after land preparation) a) fish meal .... b) rice/barn/gram .... c) molluscs/snail .... d) oil cake .... e) lime .... f) other (specify)				
6. Medicine for disease/parasite control:				
7. Harvesting: (how many times)	wages for fishermen			
	rent for fish net .... total labour	....	....	
8. Transportation and marketing				
9. Guard room and other infrastructure .... Salary of the guard(s)		....	....	....
10. Materials (e.g., fencing net, bamboo etc.) for protecting fish from the overflowing of gher.				
11. Other costs				

3.4 Information regarding fishmeal, pest control and watering/dewatering

a) Do you know the appropriate dose of fish feed? Yes / no
b) If yes, have you applied the appropriate dose? Yes / no

3.5 Total production of fish from the specific gher

Variety	Annual production (kg)	Price (kg)	Total return (Tk.)
Bagda			
Golda			
White fish			

3.6 The nature and sources of technological knowledge and logistic support

a. Nature and extent of extension services

i) Do you maintain contact with the fishery field supervisor? ....Yes/ No.
If yes, then what is the frequency? ....days in 3-months

ii) Have you had any training in fish farming? Yes/ No.
If yes, what was the topic and length of the training period? .... days

b. Have you taken a loan for fish farming activities? Yes/ No
If yes, what are the sources of your loan?

Thank you very much for your valuable information

Name of the enumerator:..

Signature:............................ date: ....

Appendix 6

Pearson Correlation with Zero Rank for Exogenous and Endogenous Variables Used in Stochastic Production Frontier

Table 6A: Bivariate correlations between exogenous and endogenous variables in the econometric model for paddy production with SRM

Particulars	Pearson Correlation with zero rank									
Variables	Symbols	x_1	x_2	x_3	x_5	x_6	x_7	x_8	x_{10}	y
Seed cost/acre	x_1	1								
Dewatering (lit)/acre	x_2	.046	1							
Land prep cost/acre	x_3	.078	.098	1						
Urea (kg)/acre	x_5	.111	-.060	-.083	1					
TSP (kg)/acre	x_6	-.130	.042	.125	.145*	1				
MP (kg)/acre	x_7	.127	.143*	-.081	.317**	.079	1			
Irrigation (lit)/acre	x_8	.211**	-.147*	.102	.161*	-.027	.116	1		
Labour days/acre	x_{10}	.368**	.114	.057	.292**	-.093	.148*	.422**	1	
Yield (kg)/acre	y	.272**	-.241**	.007	.227**	.228**	.113	.164*	.178*	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 6B: Bivariate correlations between exogenous and endogenous variables in the econometric model for paddy production with TRM

Particulars	Pearson Correlation with zero rank								
Variables	Symbols	x_1	x_2	x_4	x_5	x_6	x_7	x_9	x_{10}	y
Seed cost/acre	x_1	1								
Dewatering (lit)/acre	x_2	.037	1							
Land prep cost/acre	x_4	-.049	.202*	1						
Urea (kg)/acre	x_5	.119	.089	.170*	1					
TSP (kg)/acre	x_6	.125	.160*	.124	.301**	1				
MP (kg)/acre	x_7	.129	-.058	.041	.137	.247**	1			
Irrigation (lit)/acre	x_9	.143	-.200*	.057	.371**	.046	.133	1		
Labour days/acre	x_{10}	.147	-.060	.027	.226**	.278**	.228**	.158	1	
Yield (kg)/acre	y	.214**	.289**	.113	.403**	.178*	.106	.105	.356**	1

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Appendix 7

Pearson Correlation with Zero Rank for Exogenous and Endogenous Variables Used in the Stochastic Cost Frontier

Table 7A: Bivariate Correlations between exogenous and endogenous variables in the econometric model for fisheries production with SRM

	Pearson Correlations with zero rank						
Variables	Symbols	x_1	x_2	x_3	x_4	x_6	c
Fingerling price/000	x_1	1					
Land prep cost/acre	x_2	.031	1				
Feed price/kg	x_3	-.034	.040	1			
Medicine cost/acre	x_4	.128	.364**	.103	1		
Yield kg/acre	x_6	.085	.406**	.014	.430**	1	
Total cost	c	.210**	.531**	.128	.572**	.790**	1

** Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

Table 7B: Bivariate Correlations between exogenous and endogenous variables in the econometric model for fisheries production with TRM

Particulars	**Pearson Correlations with zero rank**						
Variables	Symbols	x_1	x_2	x_3	x_4	x_6	c
Fingerling price/000	x_1	1					
Land prep cost/acre	x_2	.101	1				
Feed price/kg	x_3	.241**	-.118	1			
Medicine cost/acre	x_4	.030	.021	.030	1		
Yield kg/acre	x_6	.142	.284**	.137	.149	1	
Total cost	c	.326**	.307**	.208*	.179*	.625**	1

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

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